PREDICTION OF PRESSURE DROP FOR TWO-PHASE FLOW IN VERTICAL PIPES USING ARTIFICIAL INTELLIGENCE

BY

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DEDICATION

To my parents who made me the man I am today.

To my wife, Maya, who supported me and provided all the encouragement, dedication and patience..

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I would like to offer my sincere gratitude to the thesis committee for providing support, guidance and technical advice throughout my thesis.

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THESIS ABSTRACT

NAME OF STUDENT : Ahmad Tariq Al-Shammari

TITLE : Prediction of Pressure Drop for Two-Phase Flow in Vertical Pipes using Artificial Intelligence

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One of the significant parameters affecting flow rate in oil production wells is the pressure drop between the well bottom-hole and tubing head. The pressure drop calculation in two-phase flow systems is very complicated due to the variations in gas and liquid flow rates across the two-phase flow stream. As the pressure of crude decreases while climbing a well tubular, more gas comes out of solution. This gradual increase in gas volumes leads to the reduction of liquid slip velocity and creating new flow patterns that are not only different in shape, but also complicated in pressure drop calculations. To overcome this difficulty in calculating pressure drop in two-phase flow systems, scientists came up with two main approaches: flow correlations and mechanistic models. These two approaches are applicable within certain conditions and their accuracy in pressure drop prediction degrades outside their design boundary ranges.

The raising popularity of Artificial Intelligence (AI) techniques during the past two decades proved that AI can be an alternative solution to many of the complicated problems where physics and classic statistics fail to provide satisfactory solutions. These techniques applied in different upstream fields have provided fast, robust and reliable numerical models

in a variety of areas, e.g., geological modeling, reservoir engineering, petrophysics and well testing. This thesis describes the utilization of Fuzzy Logic, which is one of the famous AI techniques, in predicting flowing bottom-hole pressure in oil producer wells. Real well testing data from the Middle East were used in constructing the Fuzzy Logic model. After training the model using 596 well testing data samples, it was successfully able to predict the flowing bottom-hole pressure at 199 well testing samples with an average absolute error of 4.9%. A comparison analysis was conducted to evaluate multiple flow correlation in predicting flowing bottom-hole pressure and compare their results with the developed Adaptive Neuro-Fuzzy Inference System (ANFIS) model.

ملخص الرسالة

اسم اللطالب : أحمد طارق الشمري

عنوان الرسالة : التنبؤ بانخفاض الضغط للتدفق ثنائي الطور في الإنابيب العمودية باستخدام الذكاء الاصطناعي

التخصص : هندسة البترول

تاريخ التخرج : صفر 1433 هـ

إن مقدار انخفاض الضغط بين قعر البئر وفوهته في آبار النفط يعد من أهم العوامل التي تؤثر بشكل مباشر في مقدار التدفق. لكن حساب مقدار انخفاض الضغط في التدفق ثنائي الطور يعتبر من العمليات المعقدة بسبب التغير في نسب الغاز والسائل عبر أنبوب البئر العمودي، حيث أن انخفاض الضغط يتسبب في زيادة نسب الغاز المتحررة من السائل وذلك بشكل تصاعدي مما ينتج معه خلق أنماط تدفق جديدة. هذه الأنماط هي ليست مختلفة فقط بالشكل ، ولكن أيضا في العوامل المؤثرة في هبوط الضغط. للتغلب على هذه الصعوبة في حساب انخفاض الضغط في التدفق ثنائي الطور، استخدم العلماء أسلوبين رئيسيين: العلاقات الرياضية للتدفق و النماذج الآلية. هذان الأسلوبان قابلان للتطبيق ضمن نطاقات معينة ودقتهما في التنبؤ بانخفاض الضغط تقل خارج هذه النطاقات.

أثبتت زيادة شعبية الذكاء الاصطناعي (AI)خلال العقدين الماضيين أن هذه الطريقة الرياضية يمكن أن توفر حلولا فعالة لكثير من المشاكل المعقدة التي تفشل الفيزياء الكلاسيكية والطرق الإحصائية في حلها. وقد وفرت هذه التقنيات نماذج رقمية سريعة وموثوق بها في العديد من المجالات كالتمثيل الجيولوجي، هندسة المكامن، الفيزياء النفطية وفحص الآبار.

هذه الأطروحة تشرح استخدام المنطق الضبابي، والذي يعد من أهم التقنيات في الذكاء الاصطناعي، في التنبؤ بقيمة الضغط في قعر الآبار المنتجة النفط. ولبناء نموذج المنطق الضبابي استخدمت 596 مجموعة من البيانات الحقيقية المأخوذة من دراسات فحص الآبار لآبار من الشرق الأوسط. وكان النموذج قادرا على التنبؤ بقيمة الضغط في قعر البئر لـ 199 مجموعة من البيانات الأخرى التي استخدمت لفحص دقة النموذج الضبابي والتي نتج عنها مقدار خطأ متوسط مطلق يعادل 4.9% . وأجري تحليل مقارنة بين نموذج المنطق الضبابي والعديد من نماذج ارتباطات التدفق الشهيرة للتنبؤ بقيمة الضعط في قعر البئر وذلك لمقارنة أداء هذه النماذج مع طريقة "نظام الاستدلال العصبي الضبابي المتكيف" (ANFIS)

درجة ماجستير العلوم

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CHAPTER 1

INTRODUCTION

Two phase flow is an expression that refers to systems containing simultaneous flow of gas and liquid. Historically, this type of flow has been studied in power systems, in which pressurized water along with steam flow together in boilers and heat exchangers. Moreover, flow of steam and water is studied in nuclear reactors that utilize water for cooling reactor cores. In the petroleum industry, the two phase flow behavior grasp great attention as it affects the whole oil and gas production system from the reservoir up to the refinery.

Petroleum fluid is composed of multiple organic components that vary in molecular weight. The molecular weights and mass percentages of these components within a petroleum reservoir fluid define its properties such as density, viscosity and bubble point pressure, below which gas phase start to appear as a separate fluid.

In oil reservoirs with pressures above the bubble point, the main fluid phase is liquid regardless of the percentage of the gas phase that is in solution. However, as the crude enters the wellbore, the pressure starts decreasing vertically until the bubble point pressure is reached. The gradual decrease in the pressure within a production tubing results in releasing greater amounts of gas bubbles that start slipping over the liquid phase and accumulating to form larger bubbles or slugs and new flow patterns will appear as illustrated in Figure 1.1.

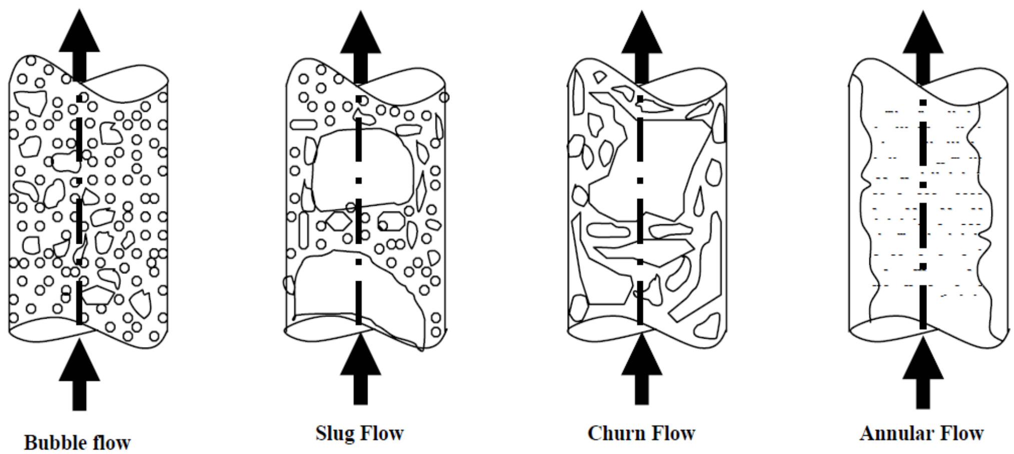

Figure 1.1: Two-Phase Flow Patterns

As a result of forming the different flow patterns in oil-producer wells, the pressure drop calculations are complicated and require deep understanding of many parameters such as liquid holdup, mixture density, two-phase Reynolds number…etc. The pressure drop prediction however is very important for petroleum engineers. Pressure losses in oil and gas wells are used in designing tubing sizes, completion configurations, and artificial lift requirements and to predict the flowing bottom-hole pressure.

The utilization of Artificial Intelligence (AI) techniques in the petroleum industry has gained a considerable attention during the past few decades. These techniques have provided solutions to a large number of problems in determining several geological, petro-physical and petroleum engineering parameters that are difficult to tackle using classical physics or engineering concepts. The present study focuses mainly on developing a new Fuzzy Logic model, which is one of the important AI techniques, to be used in predicting pressure for vertical oil-producer wells.

The report is composed of six chapters. Chapter 2 focuses on the literature review that briefly describes the approaches of pressure drop calculations in two phase flow systems and the use of fuzzy logic in the petroleum industry. Chapter 3 presents the statement of the problem and defines the general objectives. In Chapter 4, the basic concepts of Fuzzy Logic and the Adaptive Neuro-Fuzzy Inference System are presented. The results and analysis discussions are described in detail in chapter 5, and finally, the conclusions and recommendations are stated in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

Fluid flow rate in a pipe is directly proportional to the pressure difference between the pipe inlet and outlet. Considering a pipe with fixed inside diameter and fluid flow under steady-state conditions, there are two main types of pressure losses: gravitational and frictional. This chapter discusses the main concepts and equations for determining pressure drop in oil wells. In addition, a section that reviews the application of Fuzzy Logic in the petroleum industry is added.

2.1 Gravitational Pressure Drop

Gravitational pressure drop occurs only if there is a change in elevation between a pipe inlet and outlet. Gravitational pressure difference is directly proportional to the vertical elevation change and the fluid specific gravity. The amount of pressure drop in field units due to gravity can be calculated using equation[1]2-1:

$$\Delta P_{Gravity}(psi) = 0.433\ SG_m\ L\ \sin\theta^{o} \quad (2.1)$$

Where: SGm is the mixture specific gravity, L is tubing depth (ft) and θ is the inclination angle

In oil producer wells with low to average GOR values, the gravitational pressure drop is the major contributor to the total pressure losses between a well sand-face and tubing head. In oil wells with GOR values around500 scf/bbl, 80 – 85% of the total pressure drop is due to

[1]"Sami Al-Nuaim, class lecture for "Advanced Well Performance", KFUPM, March, 2009"

gravitational losses and the rest would be mostly frictional. As the GOR increases, frictional pressure losses start to dominate the total pressure drop due to the increase in fluid mixture velocity and the reduction of liquid holdup.

2.2 Frictional Pressure Drop

Frictional pressure loss occurs due to shear forces acting against fluid flow direction. The frictional losses happen near the pipe inner surface due to the molecular interconnectivity forces that resist the deformation. These forces are directly proportional to the kinetic energy of the fluid element and to the friction factor, which can be determined experimentally. Several scientists tried to correlate the friction factor with different flow parameters.

In 1944, Lewis Moody published "Friction Factor for Pipe Flow" (1). The work of Moody has become the basis for many of the calculations on friction loss in pipes. Colebrook and White came up with an implicit relationship (Equation 2.2) for calculating friction factor (2).

$$\frac{1}{\sqrt{f}} = 1.74 - 2\log\left(\frac{2\varepsilon}{d} + \frac{18.7}{N_{\mathrm{Re}}\sqrt{f}}\right) \quad (2.2)$$

This equation was then solved by Swamee and Jain (3) to give an explicit approximated solution as in equation 2.3:

$$\frac{1}{\sqrt{f}} = 1.14 - 2\log\left(\frac{\varepsilon}{d} + \frac{21.25}{N_{\mathrm{Re}}^{0.9}}\right) \quad (2.3)$$

Where ε the absolute pipe roughness (ft), d is the pipe diameter (ft) and N_{Re} is Reynolds number

The pressure drop due to friction in single phase can be calculated as[2]:

$$\Delta P_f\,(\text{psi}) = 1.8375 * 10^{-7}\,\rho\, f\, L\, \frac{q^2}{d^5} \quad (2.4)$$

[2] "Sami Al-Nuaim, class lecture for "Advanced Well Performance", KFUPM, March, 2009"

Where: ρ is the single phase fluid density (lb/ft^3), f is the friction factor (dimensionless), L is tubing depth (ft), q is flow rate (bpd) and d is tubing diameter (in)

2.3 Pressure Drop Calculations in Oil Producer Wells

As described above, the total pressure drop in oil wells is mainly composed of gravitational and frictional pressure drops. In order to calculate the total pressure drop along a production tubing section, one needs to determine the amounts of gas and liquid and trace their changes vertically. The vertical flow inside a tubing section is accompanied with pressure reduction and as the pressure reaches the bubble point, gas bubbles begin to be released. These bubbles slip vertically through the liquid column and start to accumulate as more bubbles are formed with the pressure decrease. The accumulation of gas bubbles results in forming larger bubbles that grow more as the flow climbs the tubing section, creating what is called slug flow. As the pressure continues to decrease and yet more gas is still to be released out of solution, the gas phase might transform into continuous phase at the center of the pipe and oil phase will flow as a thin fluid ring on the inside wall of the tubing. These different fluid-gas phase patterns are known as flow regimes, which are predicted based on empirical formulas that were mostly developed numerically in the lab. It is obvious that both gravitational and frictional pressure losses will be different depending on the flow regime type, which results in complicating the approaches for calculating total pressure drop in oil wells.

Typically; the two-phase flow correlation approaches calculate pressure drop by dividing the wellbore into segments and then determining the pressure drop iteratively in all segments, which eventually leads to calculating the pressure at flow stream outlet. This is illustrated in Figure 2.1.

For determining BHP starting from WHP, the process can be described as follows:

1. Divide the wellbore into segments.
2. Assume P2 at the first segment outlet.
3. Calculate average pressure of the segment based on P1 and assumed P2.
4. Calculate GOR and FVF for Oil & Gas at Pave to come up with liquid holdup.
5. Determine flow pattern based on holdup and inclination angle.
6. Calculate two phase density at Pave.
7. Calculate ΔP gravity.
8. Find Reynolds number and friction factor.
9. Calculate ΔP friction.
10. The pressure at outlet P2 is calculated based on P2 = P1 – Δ P total.
11. Compare calculated P2 with the initially assumed P2. If they match within a tolerance, then consider P2 to be the inlet pressure for the subsequent segment. Otherwise, consider P2 (assumed) = P2 (calculated) and go to step #2.

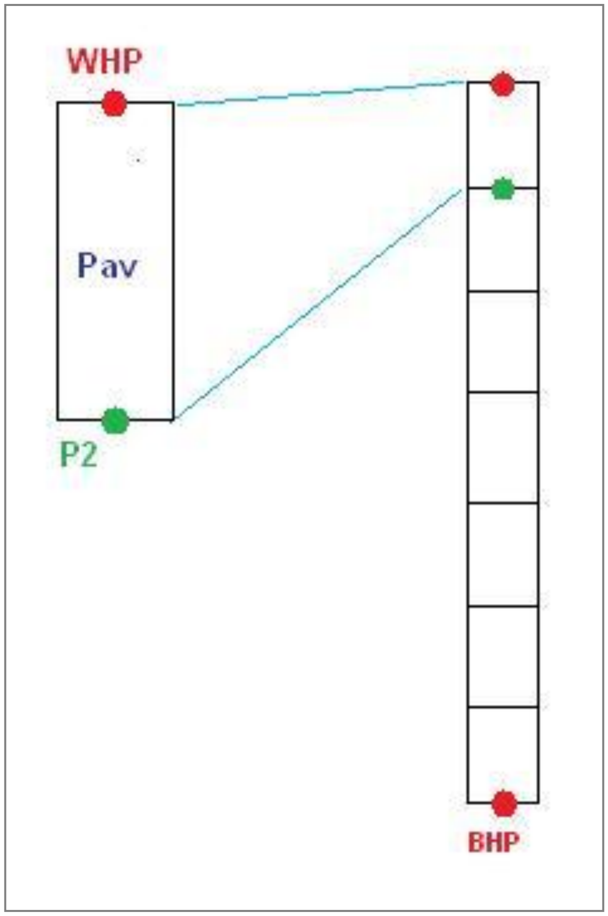

Figure 2.1: Pipe segmentation to calculate pressure drop iteratively

The previous steps indicate the complexity in calculating pressure drop for oil producer wells using two-phase flow correlations. Most of the computation steps involve the utilization of empirical correlations that were developed based on statistical and curve fitting techniques.

Majority of the developed two-phase flow correlations and mechanistic models were constructed with limited conditions and their error in predicting pressure drop tends to increase as the conditions start deviating from the design boundaries. There is no available single correlation or mechanistic model that can be applicable for all ranges of production such as GOR, liquid rate, tubing size or watercut. (4)

Recently, there were some studies that started tackling calculating pressure drop in two-phase flow systems using one of the Artificial Intelligence techniques which is the Artificial Neural Networks. In 1995, Terniyik, Bilgesu and Mohaghegh introduced the implementation of ANN in calculating flowing bottom-hole pressure in vertical and inclined pipes. They called this methodology: Virtual Measurement in Pipes (VMP). They used two sets of data and developed two separate neural network models. The first one was with pressures ranging between 100 and 10,000 psig and second was for pressure values less than 100 psig (5). In 2005, Osman, Ayoub and Aggour used neural networks in predicting bottom-hole pressures for vertical wells. They used initially a total of 386 field data sets published by Al-Muraikhi et al and collected from Middle East fields. They first tested the data against multiple empirical correlations and mechanism models and removed data sets that were poorly modeled by all correlations and models. After removing the "outliers", 206 data points were then used to develop and ANN model (6). A very similar recent study was introduced by Mohammadpoor et.al. in 2010 based on Iranian well test data. They also used ANN to predict flowing bottom-hole pressure (7).

2.4 The Use of Fuzzy Logic in the Petroleum Industry

Fuzzy Logic has been used in several petroleum engineering-related applications. These include petrophysics and permeability determination, stimulation candidate selection, production optimization and completion and multilateral design.

In 2000, S.J Cuddy (8) described the application of Fuzzy Logic in determining litho-facies and permeability in un-cored wells. In his study, he used data for 10 cored wells to derive litho-facies and permeability in 30 un-cored wells.

Ali Garrouch, et. al. of Kuwait University (9) developed in 2003 a new Fuzzy Logic for designing optimal multilateral well configuration and completion. They formulated reservoir candidate screening criteria for applying multilateral technology, and implemented these criteria in a new expert system that features the use of fuzzy logic for handling ambiguity in completion scenarios.

Similar to Cuddy methodology in finding permeability, in 2005, M. Amabeoku et. al. published a paper describing the use of Fuzzy Logic to model and predict permeability in cored wells by calibrating core permeability against conventional open-hole logs (10). The permeability models developed were then used to generate permeability trace in each well across a field.

Fuzzy logic was also used to predict reservoir fluid viscosity. In 2007, Yasin Hajizadeh published this work which included using both ANN and fuzzy logic in predicting oil viscosity (11). He used both techniques to recognize the pattern between the given data sets where this patter may not be understood clearly or no precise mathematical relationship exists.

One of the recent studies that utilized Fuzzy Logic modeling was to determine inflow performance relationship in horizontal oil wells. This study was conducted by Ebrahimi, M in 2010 (12). The author tried two neuro-fuzzy models, including Local Linear Neuro-Fuzzy Model and Adaptive Neuro Fuzzy Inference System and compared the performance with empirical correlations to predict inflow performance of horizontal oil wells experiencing two phase flow. The prediction of flowing bottom-hole pressure

CHAPTER 3

STATEMENT OF THE PROBLEM AND OBJECTIVE

This chapter describes the problem of estimating flowing bottom-hole pressure for oil wells. The importance of developing a new model that provides results with relatively higher accuracy and wider applicability ranges of field data is addresses by stating the objective of the study.

3.1 Statement of the Problem

One of the significant parameters affecting flow rate in oil-producer wells is the pressure drop between the well bottom-hole and tubing head. The pressure drop calculation in two-phase flow systems is very complicated due to the variations in gas and liquid flow rates across the two-phase flow stream. As the pressure of crude decreases while climbing a well tubular, more gas comes out of solution. This gradual increase in gas volumes leads to the reduction of liquid slip velocity and creating new flow patterns that are not only different in shape, but also complicated in pressure drop calculations. To overcome this difficulty in calculating pressure drop in two-phase flow systems, scientists came up with two main approaches: flow correlations and mechanistic models. However, these two approaches are applicable within certain conditions and their accuracy in pressure drop prediction degrades outside their design boundary ranges.

3.2 Objective

The main objective of this study is to develop a fuzzy logic model that provides more accurate prediction of flowing bottom-hole pressure in vertical oil-producer wells. Well testing data sets from different fields in the Middle East are used in the study. Specific objectives are:

1- To construct an Adaptive Neuro-Fuzzy Inference System (ANFIS) to predict flowing bottom-hole pressure in vertical multiphase flow

2- To test the developed model against actual field data

3- To compare the performance of the developed model against several famous empirical correlations.

CHAPTER 4

FUZZY LOGIC

In this chapter, we briefly discuss the main concepts of fuzzy logic, the degree of membership and membership functions, the fuzzy (if-then) rules, the fuzzy inference system (FIS) and finally, the adaptive neuro-fuzzy inference system (ANFIS).

4.1 What is Fuzzy Logic?

The term “Fuzzy” refers usually to uncertainty, ambiguity or something not well defined. Most of the natural physical properties can be described by non-crisp terms such as hot, cold, bright, hard, strong… etc. The human thinking, reasoning and decision making processes are also not crisp. We use vague, imprecise words to explain our thoughts or communicate with one another (13). Fuzzy systems are usually used to represent uncertainty that is caused by inaccuracy or ambiguity of the data or lack of the input parameters that have important influence on results. In fuzzy systems, an item or a property can be described by classifying it under one of different non-crisp sets in addition to a degree of membership to each set. (14)

The concept of Fuzzy Logic evolved from the fuzzy set theory that was proposed by a mathematician of Iranian descent: Dr. Lotfi A. Zadeh in 1965. Dr. Zadeh is considered the father of Fuzzy Logic and its implementations in mathematics, computer sciences, system control and artificial intelligence. The fuzzy set theory suggests dealing with non-crisp variables by adding a truth value that ranges between 0 and 1(15).The relation between a variable and its truth value can be described by a “membership” function that ranges between 0 and 1 and the value of this variable in the functions defines a “degree” of membership.

4.2 Degree of Membership and Membership Functions

Let us take for example an AC temperature setting and define the human feeling at each temperature as different fuzzy sets. We could consider $16^{o}C$ to be cold, $22^{o}C$ as pleasant and $26^{o}C$ as hot. The three sets here are: cold, pleasant and hot and each temperature setting can belong to one of these sets at a degree of membership. Take for example, the temperature $25^{o}C$, is it pleasant or hot? Actually, it can belong to the two sets at the same time but with different degree of membership. We can say that it is not very pleasant or it is a little hot. This can be described graphically in Figure 4.1, where the membership value of $25^{o}C$ is 0.75 with Pleasant property and 0.25 with Hot property.

One way of representing fuzzy set and membership information is $\mu_A(x) = m$, where the membership μ of an item x in a fuzzy set A is m. The AC temperature example can be expressed by the following expression: $\mu_{Hot}(25) = 0.75$ or $\mu_{Pleasant}(25) = 0.25$

In fuzzy logic, unlike representing a normal set like A = {x | x is even number}, we describe fuzzy sets by coupling elements with membership functions such as $A = \{x, \mu A(x) \mid x \in X\}$. The membership functions can be simple straight lines or advanced functions such as trapezoidal, sigmoid or Gaussian. (8)

4.3 Fuzzy If-Then Rules

When the conditional statements "if $A = x$ then $B = y$" are characterized by membership functions, they are called *fuzzy if-then* rules. An example that can explain this type of rules is: *When volume is large, then density is low,* where *volume* and *density* are linguistic variables, *large* and *low* are linguistic values that are associated with membership functions. (16)

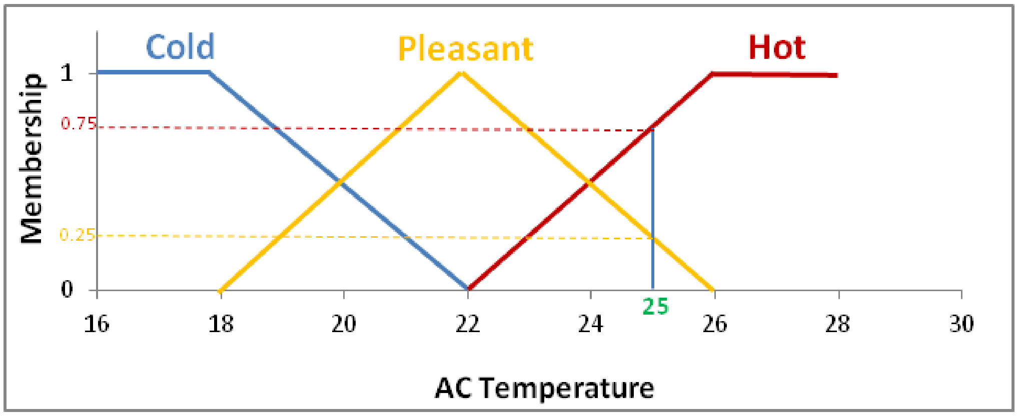

Figure 4.1: Describing Temperatures using Fuzzy Sets

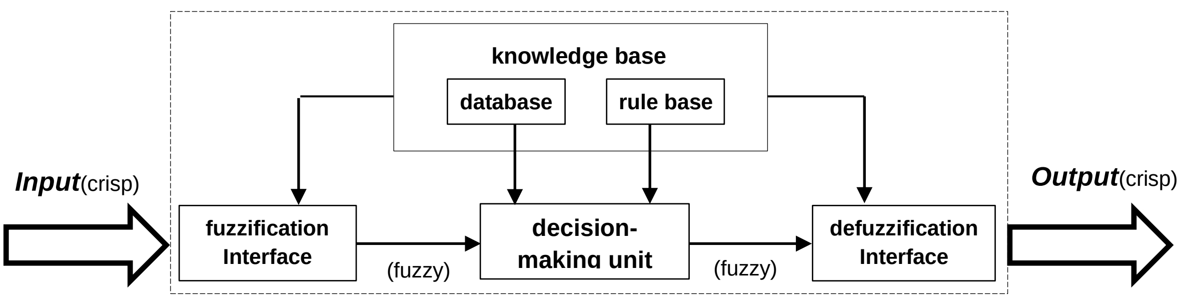

Figure 4.2: Fuzzy Inference System (FIS) Blocks, *ref:*(16)

Another type of *fuzzy if-then* rules is the Sugino-type, which includes fuzzy sets only in the premise part. An example of this type of if-then rules is: *If you are above 15, then your body mass index (BMI) = weight / height^2,* where the premise part has the term *above 15,* which is a fuzzy set and the consequent part is described by a non-fuzzy set. (16)

4.4 Fuzzy Inference Systems

Fuzzy Inference System (FIS) is the process of establishing formulated mapping from an input to an output using fuzzy logic. FIS involves combing formulating membership functions, logical operations and a group of “If-Then” rules to create a matrix of rules between input sets and an output.

Fuzzy inference systems are composed of five main blocks (see Figure 4.2):

1- Fuzification interface to transfer the crisp data inputs into degrees of match with linguistic values

2- Rule base, which contains a number of fuzzy “if-then” rules

3- Database for the membership functions of the fuzzy sets used in the rules

4- Decision making unit, which is used for the inference operations

5- Defuzzification interface, to transfer the fuzzy output into crisp results. (16)

The fuzzy inference operations include first “fuzzifying” the input variables by assigning a degree of truth between 0 and 1 to statements about the input variables in the antecedent (IF) part of the rules. The degrees of truth are determined by the membership functions. These statements are also joined by connectives (AND or OR) and the fuzzy operator resolves the overall antecedent based on the connections used. The fuzzy operator converts all the logical statements into a number between 0 and 1. (17)

4.5 Adaptive Neuro-Fuzzy Inference System (ANFIS)

ANFIS method provides a technique for fuzzy modeling process to "learn" from data sets. This method is applied to construct a FIS and tuning or adjusting the membership functions using back propagation algorithms along with least-square type functions to learn from datasets. A structure similar to neural networks is created to map inputs using input membership functions and associated parameters, and then through output membership functions and associated parameters to the outputs. ANFIS is used for constructing a set of fuzzy "if-then" rules with membership functions to generate input-output pairs. (17)

4.5.1 ANFIS Architecture

Let us consider a fuzzy inference system with two inputs *x* and *y* and one output *z*. Suppose that the rule base contains two fuzzy *if-then* rules. (16)

Rule 1: if x is a_1 and y is b_1, then$f_1 = p_1 x + q_1 y + r_1$……………………..……..(4 . 1)

Rule 2: if x is a_2 and y is b_2, then$f_2 = p_2 x + q_2 y + r_2$……………………..……..(4 . 2)

Where $f_i$is the consequent function, p_i, $q_i$and $r_i$are the consequent parameters.

The ANFIS structure is composed of 5 basic layers and each layer is composed of nodes that are equal to the number of rules.

Layer 1: This layer includes fuzzifying the input and establishing the membership degree for each rule to one of the "bell-shape" membership functions. An example of this representation is as follows:

$$\mu_{A_i}(x) = \exp\left\{-\left(\frac{x-c_i}{a_i}\right)^2\right\} \quad \text{………..…………………………….………(4 . 3)}$$

Where a_i, $b_i and\ c_i$ are the membership function parameters set that are modified during the learning process to provide acceptable output.

Layer 2: Every node in this layer multiplies the incoming signals from layer 1 and sends out the product. For example: $w_i = \mu_{A_i}(x) \times \mu_{B_i}(y)$ … … . . … . . (4.4)

The multiplication in this layer represents the rule weight and the AND operator is mainly used as the node function in this layer.

Layer 3: Each node in this layer calculates the arithmetic average of each weight to output the normalized weights: $\overline{w_i} = \frac{w_i}{w_1 + w_2}$ ……………………...………………(4.5)

Layer 4: In this layer, each normalized weight is multiplied by the consequent function: $\overline{w_i} f_i = \overline{w_i}\,(p_i\, x + q_i\, y + r_i)$ ……………..………….……………(4 6)

Layer 5: This layer is composed of a single node that calculates the overall output:

Overall Output = $\sum \overline{w_i} f_i = \frac{\sum w_i f_i}{\sum w_i}$ …………………….…...………(4.7)

CHAPTER 5

RESULTS AND DISCUSSIONS

In this chapter, data handling in terms of data collection and pre-processing is firstly discussed. Then, a detailed discussion of the developed ANFIS model, including model features and model optimization is presented. Next, a detailed trend analysis of the new developed model is presented to examine whether the model simulates the physical behavior. This is followed by a detailed discussion of the model superiority and robustness against the empirical correlations included in the study. Finally, statistical and graphical comparisons of the developed model against the correlations are presented.

5.1 Data Acquisition

Data preparation is one of the key steps in developing any AI technique. It is very important to review the data and remove outliers before using it in constructing AI models. For the current study a total of 1207 well productivity testing data sets were initially collected from several fields in the Middle East. The data sets included several key input parameters that were later used in constructing the ANFIS model. The input parameters selected were: flowing wellhead pressure, liquid rate, watercut %, gas oil ratio, oil API, reservoir temperature, tubing inside diameter and the gauge depth. The output value was the measured flowing pressure at gauge depth.

5.2 Data Preprocessing and Filtration

Well testing data is subject to uncertainty and inaccurate measurements, so it is important to filter the data and exclude all the datasets that include one or more of these inaccurate readings that might disturb the smoothness of the model learning process. The filtration process was done by applying the following steps:

1. A small computer program was written to feed well testing conditions (data sets) into Prosper software to calculate flowing bottom-hole pressure using multiple flow correlations. The correlations used were: Beggs and Brill, Duns and Ros, Hagedorn and Brown, Fancher and Brown, Mukherjee and Brill, Orkiszewski and Petroleum Experts II.
2. The relative absolute error between the predicted and measured flowing bottom-hole pressure was calculated for each of the correlations.
3. The arithmetic average error for all the correlations was computed at each dataset.
4. Datasets at which the average error is more than 15% were excluded from the study.

After filtering the data, we ended up having a total of 796 datasets. A summary of the data parameter ranges is available in Table 5.1.

5.3 ANFIS Model Development

In this study, Matlab software was used for designing and optimizing the fuzzy logic system. Matlab has a large library of functions and techniques that are used for constructing most of the AI models. There are two main types of Fuzzy Inference Systems available: Mamdani and Sugeno. In this study, we implemented Sugeno type FIS because it is more compact and has more efficient representation of the rules. (17)

Table 5.1: Collected Data Ranges of Input and Output Parameters

		Min	*Max*
Input	WHP (psig)	92	1550
	Q_{Liquid} (bpd)	639	21300
	WC (%)	0	97.5
	GOR (scf/stb)	11	6300
	Depth (ft)	4243	8620
	ID (in)	1.995	6.276
	API	25.4	47.5
	T res (^{o}f)	160	233
Output	BHP (psig)	1198	3698

Table 5.2: Collected Data Ranges of Input and Output Parameters for Training and Testing

		Training		***Testing***	
		Min	*Max*	*Min*	*Max*
Input	WHP (psig)	92	1550	170	1410
	Q_{Liquid} (bpd)	639	21230	1000	21300
	WC (%)	0	97.5	0	93.7
	GOR (scf/stb)	18	6140	11	6300
	Depth (ft)	4243	8620	4650	8478
	API	25.4	47.5	26.2	47.5
	ID (in)	1.995	6.276	2.441	6.276
	T res (^{o}f)	160	233	160	233
Output	BHP (psig)	1198	3604	1705	3698

The technique used in creating the FIS for this study was to implement subtractive clustering method that groups the data into multiple clusters and each cluster is defined by a radius of influence whose values range between 0 and 1. Small value of cluster radius results in a larger number of rules and usually tends to over fit the train in data. Each value of the input variables is then linked to a cluster by a membership function that is fine-tuned iteratively until the model predicts an output with minimal deviation from target value.

Several FIS techniques were tested in Matlab to come up with the most optimized technique. It was found that the Matlab function: "genfis2" provides superior modeling results during the training stage and hence used for further optimization. This function generates Sugeno-type FIS structure using subtractive clustering of the data and extracts rules and membership functions to model the data behavior (17).Among the 795 well testing data samples, 596 data samples (75%) were used for training and 199 (25%) for testing. Table 5.2 summarized the ranges for the training and testing data to insure most of the data ranges are similar in both.

5.4 Model Optimization

After testing several cluster radii, it was found that a cluster radius of 0.6 was the most optimized value with an average absolute error of 4.33 % and 4.92% on the training and testing data respectively. Figures 5.1 and 5.2 indicate the effect of cluster radius on the error standard deviation, the average absolute error and correlation factor between predicted and measured BHP. The figure indicates that small cluster radius has a good impact on predicting the BHP for the training data samples (Figure 5.1). However, this results in a large number of rules that almost memorized the data blindly, which has a bad influence on the prediction of the BHP using testing samples (Figure 5.2).

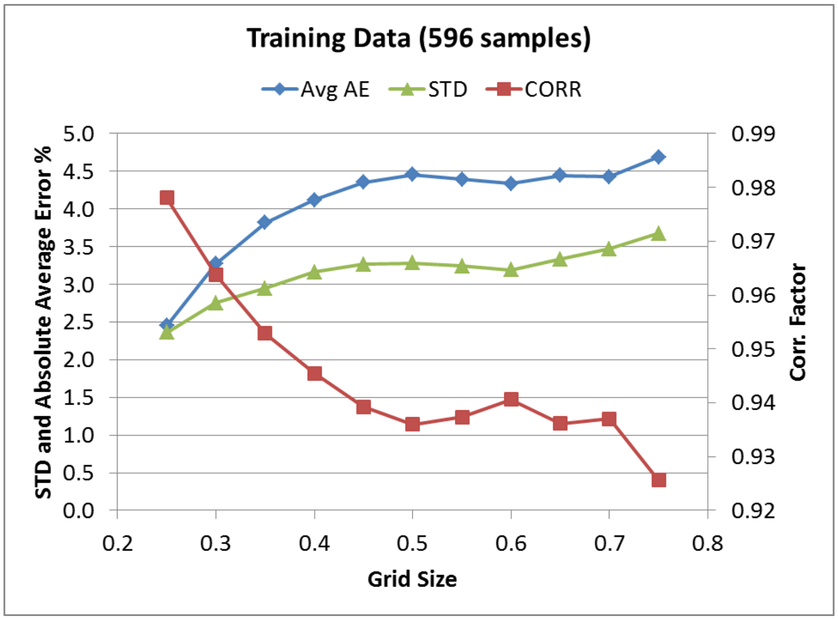

Figure 5.1: Effect of Grid Size of ANFIS Performance (Training Samples)

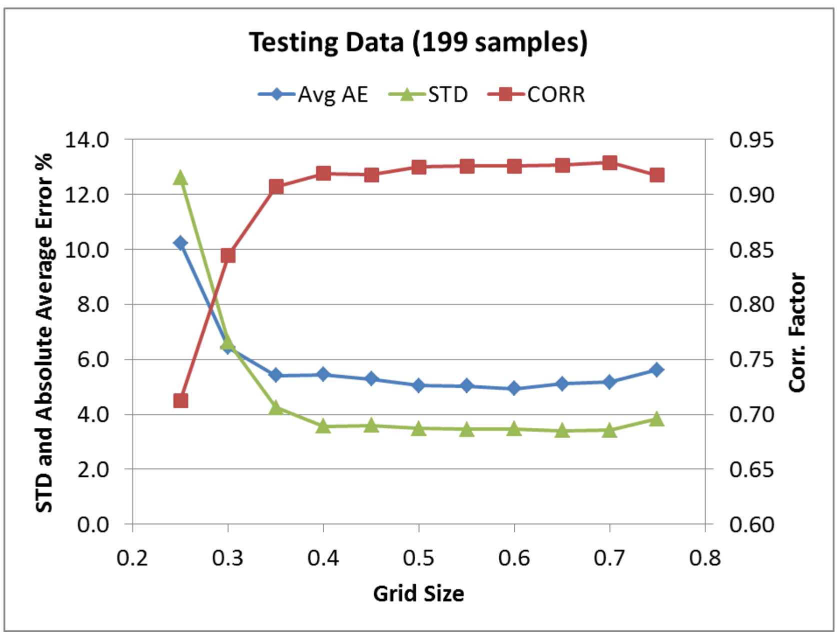

Figure 5.2: Effect of Grid Size of ANFIS Performance (Testing Samples)

5.5 Trend Analysis

The trend analysis was carried out to check the physical behavior of the developed ANFIS model. For this purpose, synthetic sets were prepared where in each set only one input parameter was changed while other parameters were kept constant. To test the developed model, the effects of gas oil ratio, oil rate, water cut%, tubing diameter, and tubing depth on flowing bottomhole pressure were determined and plotted on Figures 5.3 through 5-6. Figure 5-3 indicates the effect of increasing GOR on the predicted BHP. The ANFIS model predicted the expected trend of decreasing BHP as the GOR increases because of the reduction in hydrostatic pressure in the tubing. In Figure 5-4, the effect of increasing oil rate while keeping the water and gas rates along with other conditions constant on bottomhole prediction is shown. This oil rate increase while maintaining fixed water and gas rates results in increasing the total liquid rate and reducing the GOR, which results in higher friction and larger hydrostatic head and to overcome this increased frictional loss and hydrostatic column weight, the bottomhole pressure should increase. The ANFIS models followed the general trend of the empirical correlations and provided the expected behavior. Figure 5.5 displays the effect of increasing water cut on the predicted bottomhole pressure. The increase in water cut while keeping the oil rate constant results in increasing the total liquid rate as well as increasing the hydrostatic column head, which results also in higher bottomhole pressure. This general trend was also captured by the predicted bottomhole pressure using the ANFIS model. Finally, the effect of tubing inside diameter is shown in Figure 5.6. As the tubing size increases, the frictional pressure loss in the tubing decreases, which results in lower bottomhole pressure. The general trend was captured by the model. However, the model deviates from the overall trend at small tubing ID values. This behavior will be explained in the next section that analyzes the grouped error analysis, in which we will notice that the error in

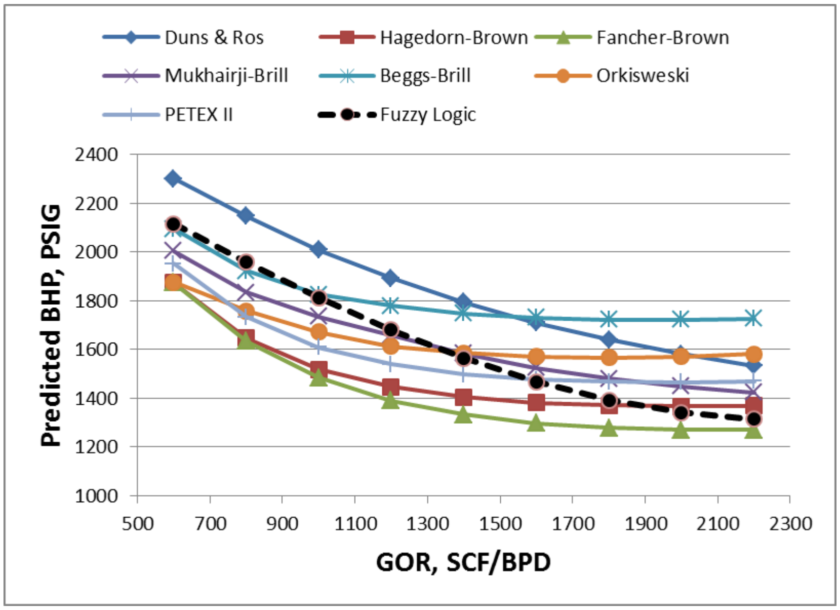

Figure 5.3: Effect of Gas Oil Ratio on Predicted BHP at: WHP=500 psig, WC=20%, QL=6000 bpd, Depth=6000 ft and Tubing ID=3.958 inches

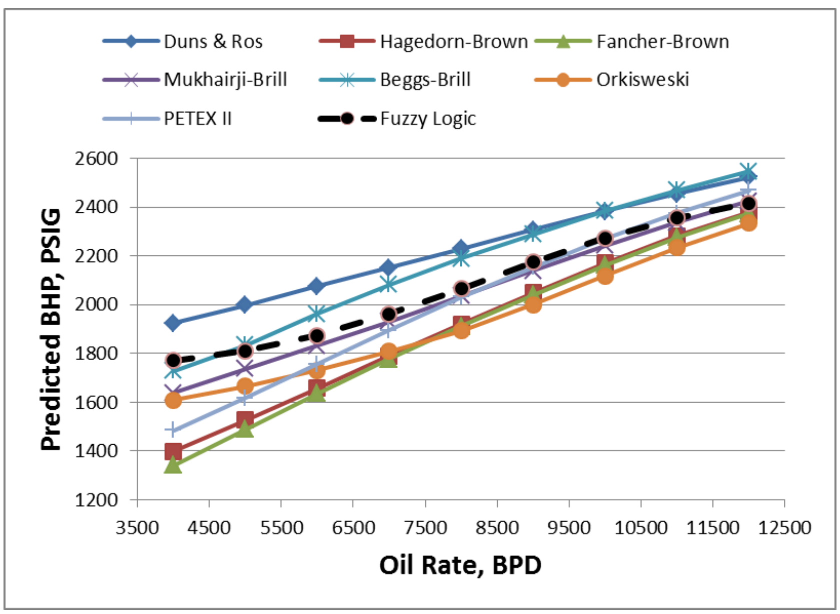

Figure 5.4: Effect of Oil Rate on Predicted BHP at: WHP=500 psig, Qw=1200 bpd, Qg=5000 Mscf, Depth=6000 ft and Tubing ID=3.958 inches

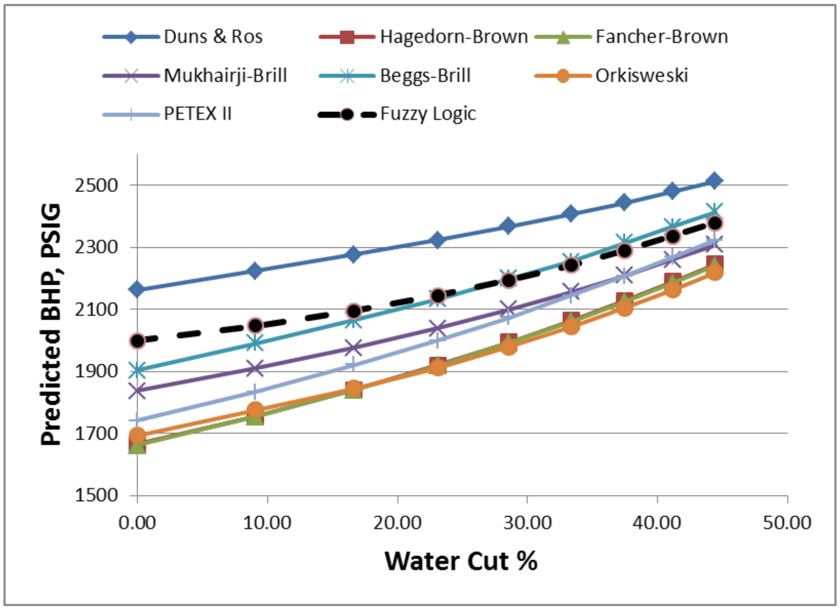

Figure 5.5: Effect of Water Cut % on Predicted BHP at: WHP=500 psig, Qo=5000 bpd, GOR=600 scf/bpd, Depth=6000 ft and Tubing ID=3.958 inches

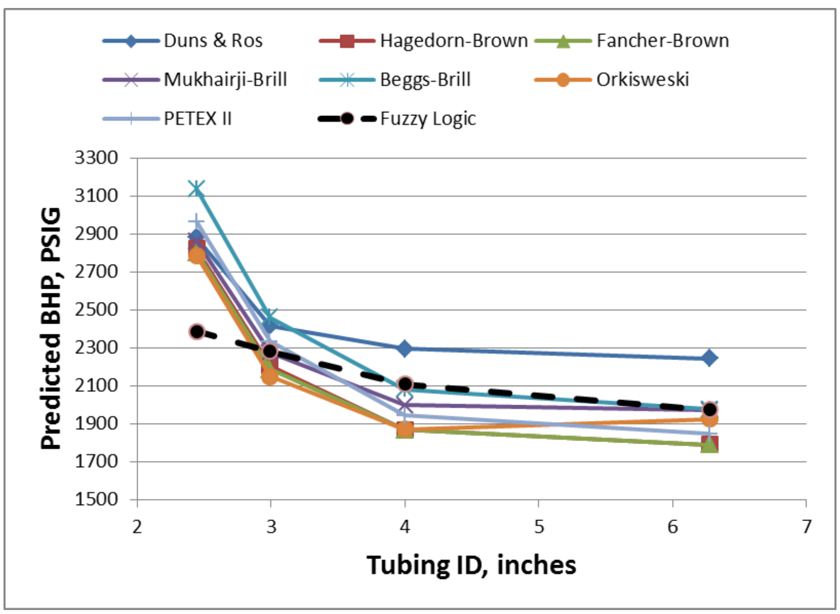

Figure 5.6: Effect of Tubing ID on Predicted BHP at: WHP=500 psig, WC=20%, QL=6000 bpd, GOR=600 scf/bpd and Depth=6000 ft

predicting bottomhole pressure using the ANFIS model is higher at smaller ID. To further examine the ANFIS model validity, the trend analysis was checked at three different tubing sizes: 2.992, 3.958 and 5 inches. Figures 5.7 to 5.10 indicate the trend analysis for oil rate, GOR, WC% and tubing depth respectively.

5.6 Group Error Analysis

Another statistical analysis was carried out to further evaluate the robustness of the developed ANFIS model, which is the group error analysis. The group error analysis provides a means for determining the strengths and weaknesses of the developed model and the empirical correlations with respect to the input data. Some models provide good accuracy at certain input data ranges and some could have positive or negative trends in the predicted values' accuracy by increasing or decreasing some input variables. The group error analysis is applied by grouping the input parameters into few averaged sets and plotting the absolute average error at each set. Figures 5.11 to 5.16 demonstrate the group error results plotted for the input parameters. The figures indicates that the ANFIS model predicts BHP values with lower average absolute error compared with the all the empirical correlations at all input parameter ranges except with respect to the API and tubing ID ranges. We notice that the ANFIS model provides relatively larger absolute error at API value of 44 and tubing ID of 2.441 inches and the reason for that is the small number of data samples that were used in the training sets. If the number of training data samples covering a certain data input value is small, then the combinations of the other different variables may not be adequate to construct reliable set of rules.

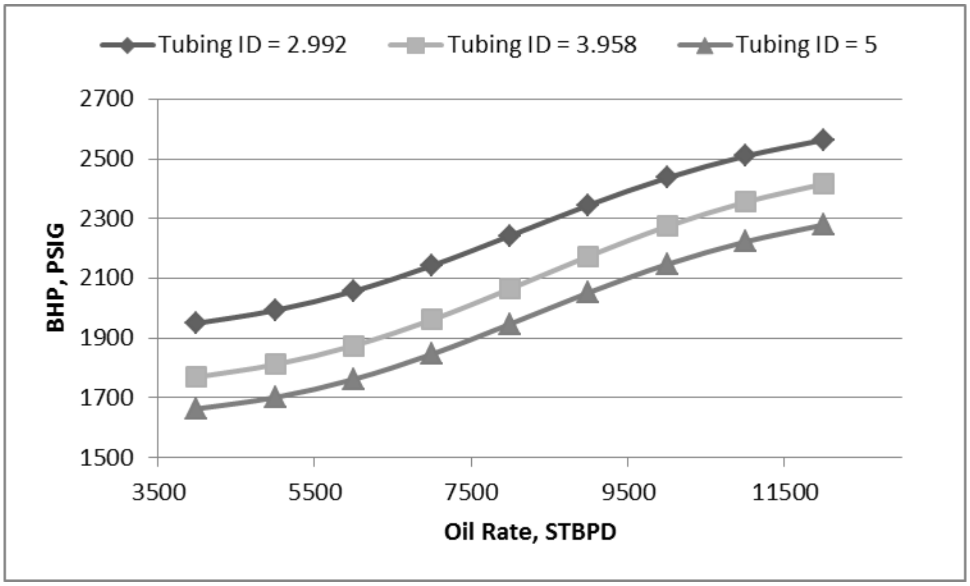

Figure 5.7: Effect of Changing Oil Rate on the Predicted BHP for Three Tubing Sizes

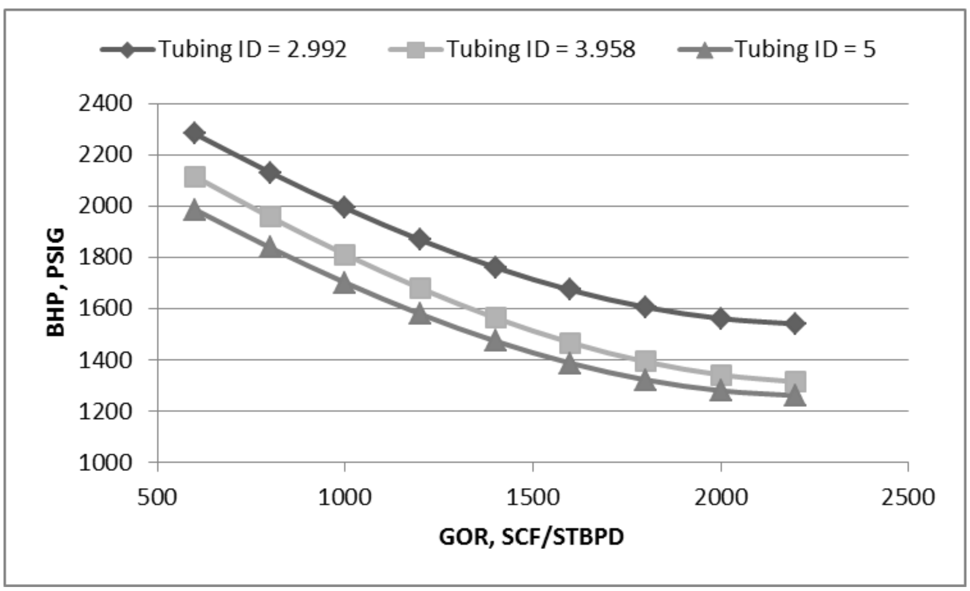

Figure 5.8: Effect of Changing GOR on the Predicted BHP for Three Tubing Sizes

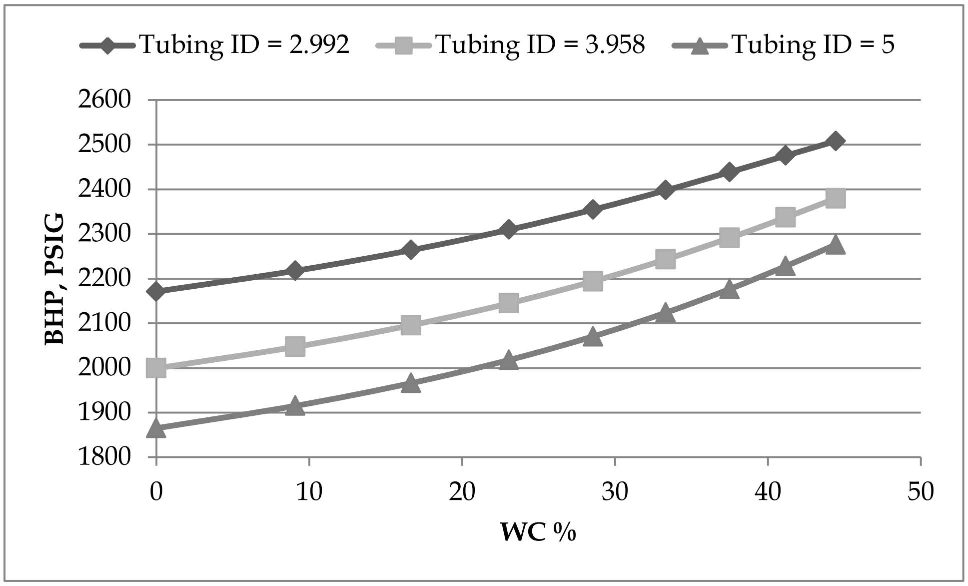

Figure 5.9: Effect of Changing WC% on the Predicted BHP for Three Tubing Sizes

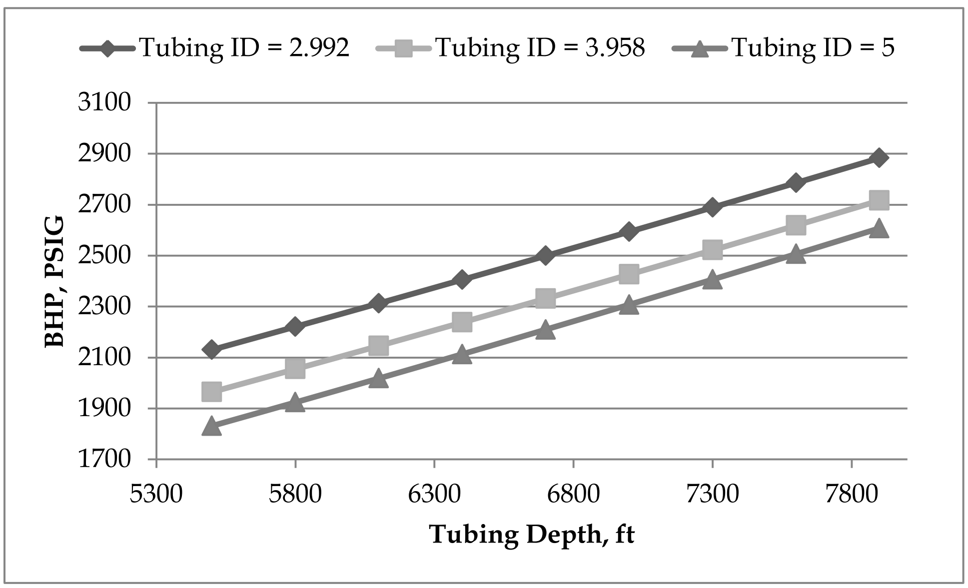

Figure 5.10: Effect of Changing Tubing Depth on the Predicted BHP for Three Tubing Sizes

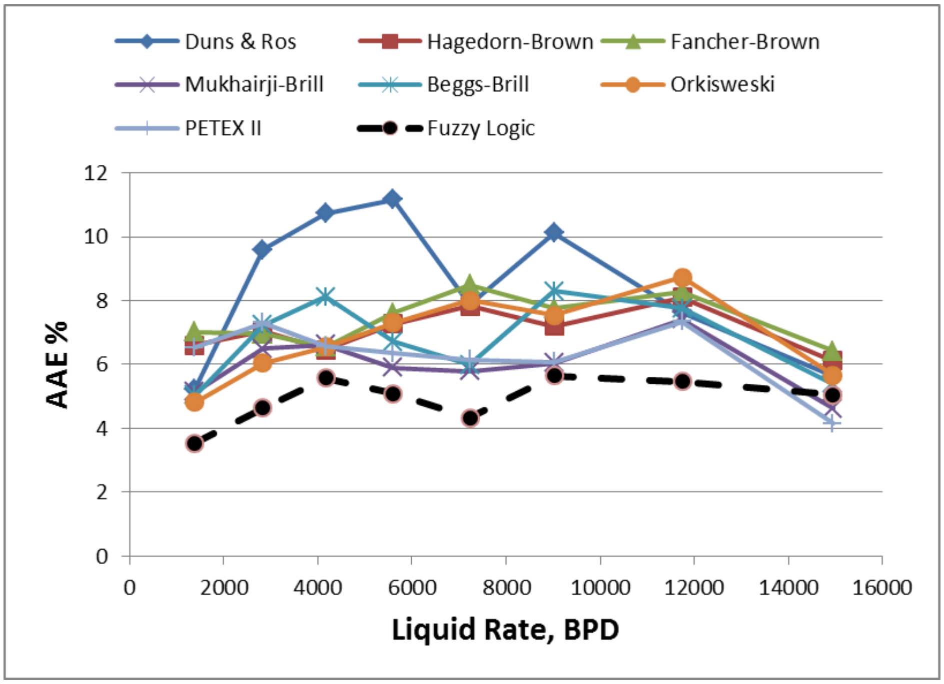

Figure 5.11: Group Error Analysis for Liquid Rate Input Data

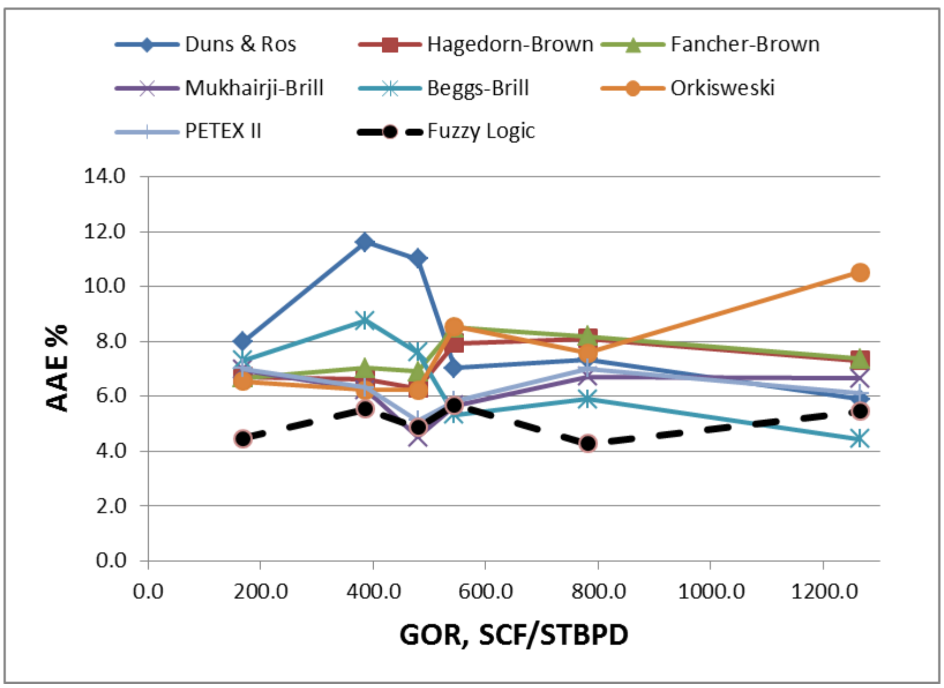

Figure 5.12: Group Error Analysis for Gas Oil Ratio Input Data

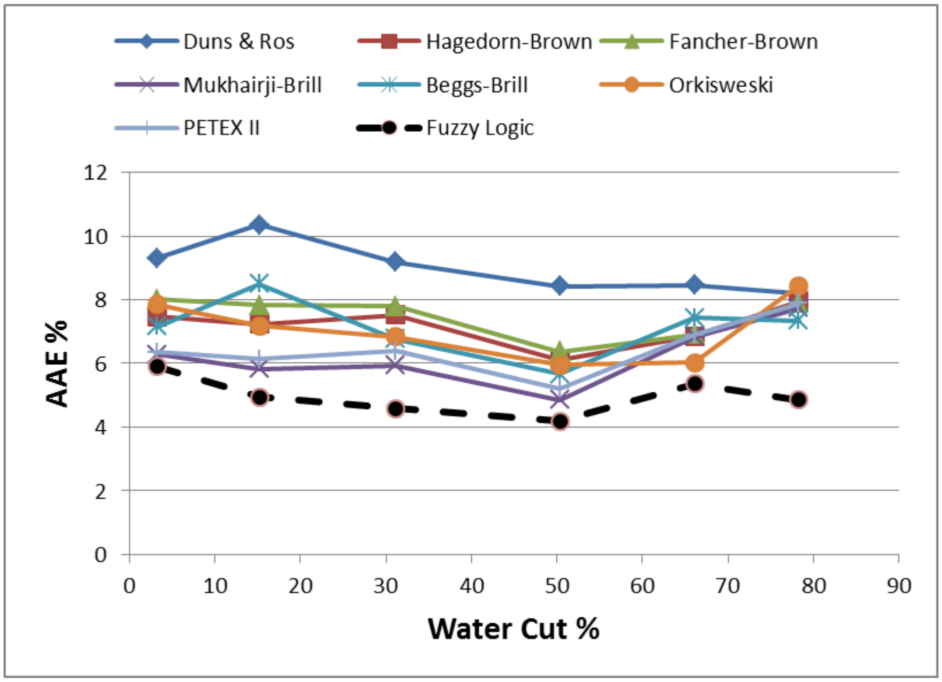

Figure 5.13: Group Error Analysis for Water Cut% Input Data

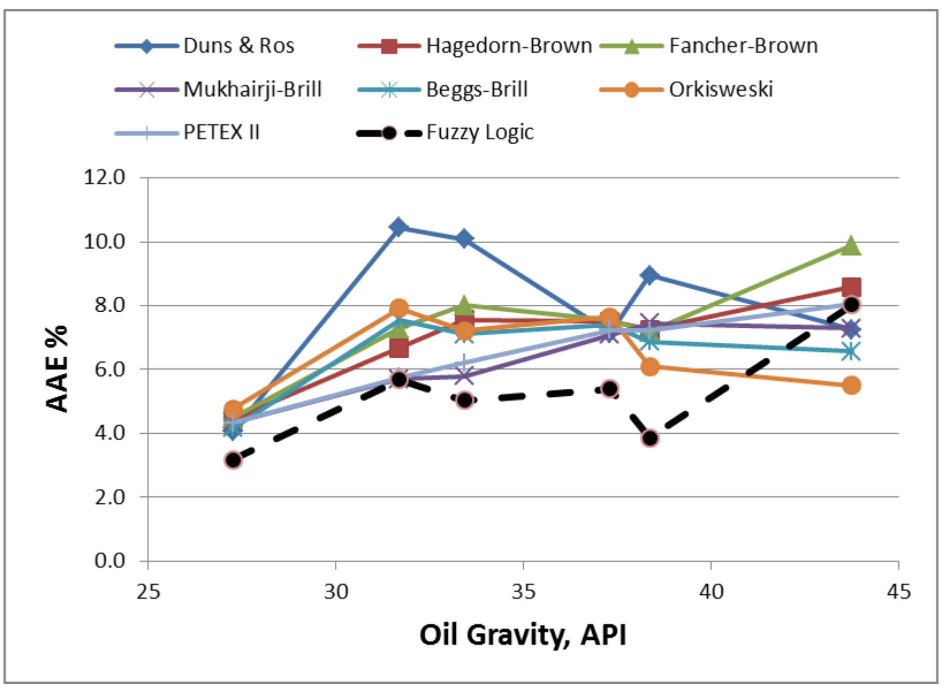

Figure 5.14: Group Error Analysis for Oil API Input Data

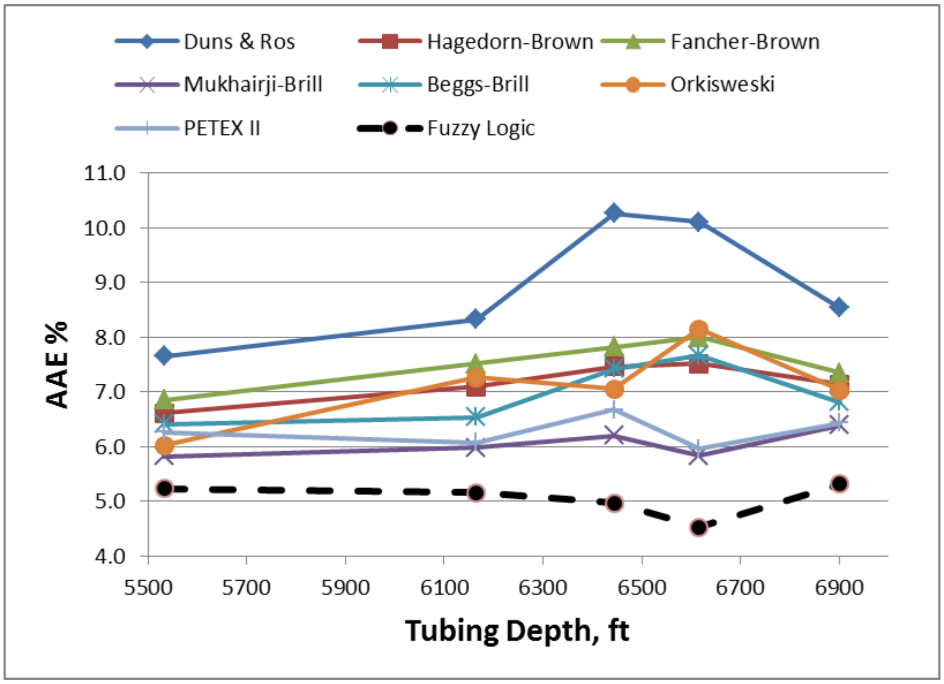

Figure 5.15: Group Error Analysis for Tubing Depth Input Data

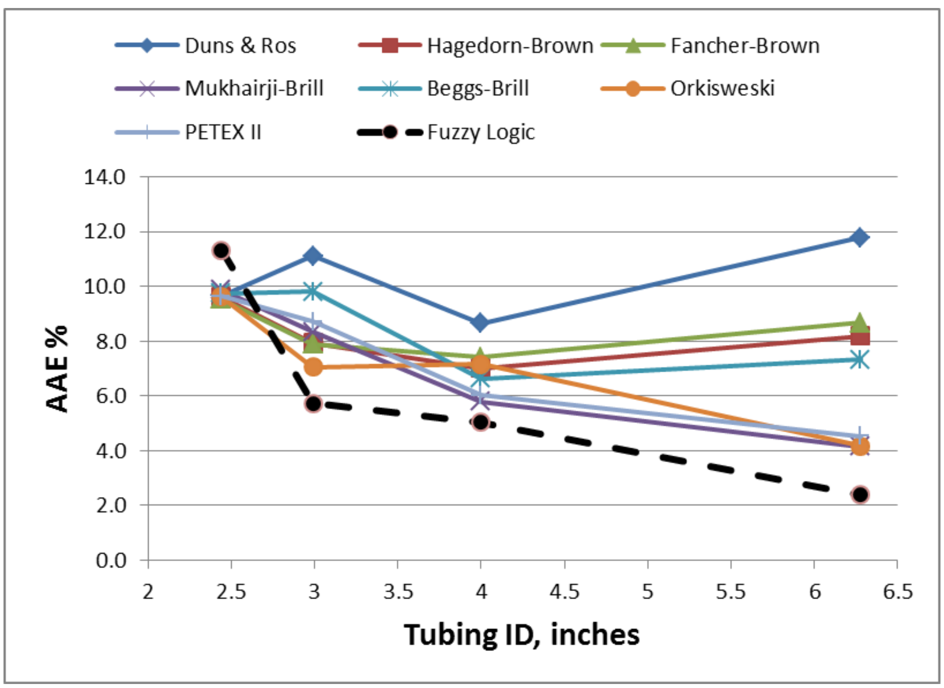

Figure 5.16: Group Error Analysis for Tubing ID Input Data

5.7 Statistical and Graphical Comparison

5.7.1 Statistical Error Analysis

The error analysis is used mainly as a basic tool for determining the robustness and accuracy of the models. The statistical parameters included in the evaluation of the developed model and the empirical correlations are: the average absolute percentage error, the maximum absolute percentage error, the standard deviation of errors and the correlation coefficient between predicted and actual BHP values. The equations for these parameters are given below. Summary of the comparison between the empirical correlation and developed ANFIS model is presented in Table 5.3. This table clearly indicates that the developed ANFIS model provided the best results in all statistical parameters. The ANFIS model was able to predict BHP with an average absolute error (E_a) of 4.93%, whereas the E_a values for the empirical models were: 6.06% for Mukherjee-Brill, 6.3% for Petroleum Experts II, 6.95% for Beggs-Brill, 7.16% for Orkiszewski, 7.21% for Hagedorn-Brown, 7.56% for Fancher-Brown and 8.94% for Duns-Ros correlation. The maximum absolute percent error of 14.91%for the ANFIS model was also the lowest compared with the empirical correlations. This maximum error for Mukherjee-Brill was 14.95%, for Petroleum Experts II was 17.56%, for Beggs-Brill was 19.21%, for Orkiszewski was 37.49%, for Hagedorn-Brown was 21.07%, for Fancher-Brown was 23.62% and for Duns-Ros was 19.31%. The correlation coefficient between the actual and predicted BHP values was the highest for the developed ANFIS model at a value of 0.93. This value was found to be 0.91 for both Mukherjee-Brill and Petroleum Experts II, 0.92 for Beggs-Brill, 0.9 for both Hagedorn-Brown and Fancher-Brown and 0.89 for both Orkiszewski and Duns-Ros. The root mean square error was also the lowest for the ANFIS model at a value of 6.03%. The RMSE value for the empirical correlations were: 7.34% for Mukherjee-Brill, 7.72% for Petroleum Experts II, 8.31% for Beggs-Brill, 8.84%

Table 5.3: Statistical Analysis Results of the Empirical Correlations and the ANFIS model

Model	E_a (%)	E_{Max} (%)	CC	RMSE(%)	STD
Duns and Ros	8.94	19.31	0.89	10.43	7.49
Fancher and Brown	7.56	23.62	0.90	9.14	8.90
Hagedorn and Brown	7.21	21.07	0.90	8.66	8.52
Orkiszewski	7.16	37.49	0.89	8.84	8.49
Beggs and Brill	6.95	19.21	0.92	8.31	6.65
Petroleum Experts II	6.30	17.56	0.91	7.72	7.60
Mukherjee and Brill	6.06	14.95	0.91	7.34	7.15
ANFIS	4.93	14.91	0.93	6.03	5.87

for Orkiszewski, 8.66% for Hagedorn-Brown, 9.14% for Fancher-Brown and 10.43% for Duns-Ros. Finally, the standard deviation of the errors was also the lowest for the results obtained by the developed ANFIS model. This value was found to be 3.48, whereas the empirical correlations were having larger values. The standard deviation of the errors for Mukherjee-Brill was 4.14, for Petroleum Experts II was 4.47, for Beggs-Brill was 4.56, for Orkiszewski was 5.18, for Hagedorn-Brown was 4.8, for Fancher-Brown was 5.14 and for Duns-Ros was 5.37.

1. Average Absolute Percentage Relative Error

This parameter measures the direct relative deviation from experimental data. It is defined as:

$$E_a = \frac{1}{n}\sum_{i=1}^{N}|E_i|$$

where: E_i is the relative deviation from an estimated value from an experimental value

$$E_i = \left[\frac{(BHP)_m - (BHP)_p}{(BHP)_m}\right] x\ 100$$

where:

$(BHP)_m$ is the measured value of the bottomhole pressure

$(BHP)_p$ is the predicted value of the bottomhole pressure

2. **Maximum Absolute Percentage Relative Error**

   This parameter measures the maximum relative deviation from among all data samples. It is defined as:

$$E_{max} = max_{i=1}^{n} |E_i|$$

3. **Correlation Coefficient**

   The correlation coefficient represents the degree of success in reducing the standard deviation. It has a value ranging between It is given by:

$$R = \sqrt{1 - \frac{\sum_{i=1}^{n}\left[(BHP)_m - (BHP)_p\right]^2}{\sum_{i=1}^{n}\left[(BHP)_m - \overline{(BHP)_m}\right]^2}}$$

4. **Root Mean Square Error:**

   The root mean square error measures the error dispersion around zero deviation. It is defined by:

$$RMSE = \frac{1}{N}\sqrt{\sum_{i=1}^{n} {E_i}^2}$$

   where: *N* is the number of testing samples.

5. **Standard Deviation of Errors:**

The standard deviation measures the dispersion or scattering of the data around the average value. In this study, the standard deviation is calculated for the distribution of the relative errors around the average relative error for each model. The equation is given by:

$$STD = \frac{1}{N-1}\sqrt{\sum_{i=1}^{n}(E_i - E_r)^2}$$

where: N is the number of testing samples.

E_r is the relative error of the data, given by: $E_r = \frac{1}{n}\sum_{i=1}^{N} E_i$

5.7.2 Graphical Results Analysis

The graphical representation of the results provides a quick and adequate understanding of the model prediction performance. In Figures 5.17 and 5.18, the measured and predicted BHP values are plotted horizontally for all the training and testing samples to indicate the excellent fit between them and demonstrate the robustness of the developed ANFIS model. To further analyze the results graphically, additional representations are generated. This includes the cross-plot, the error distribution histogram and the residual analysis.

5.7.2.1 Cross Plots

Cross-plots provide graphical representations of the correlation quality between the actual and predicted BHP values. In this technique, all estimated values are plotted against the measured values and thus a cross-plot is formed. A 45° straight line between the estimated versus actual data points is drawn on the cross-plot, which denotes a perfect correlation line. The tighter the cluster about the unity slope line, the better the agreement between the experimental and the predicted results.

Figures 5.19 through 5.26 present cross-plots for the empirical correlations and the developed ANFIS model. Investigation of these figures clearly shows that the developed ANN model outperforms all the empirical correlations models. We notice that the cross-plot for Duns and Ros model (Figure 5.19) indicates a general tendency towards under-predicting the BHP as the majority of the results are above the 45^{o}straight line. The situation is the opposite in the case of Fancher-Brown (Figure 5.20) and Hagedorn-model (Figure 5.21), where a larger portion of the data are below the 45^{o}straight line in addition to a noticeable trend towards under predicting the BHP values as they increase.

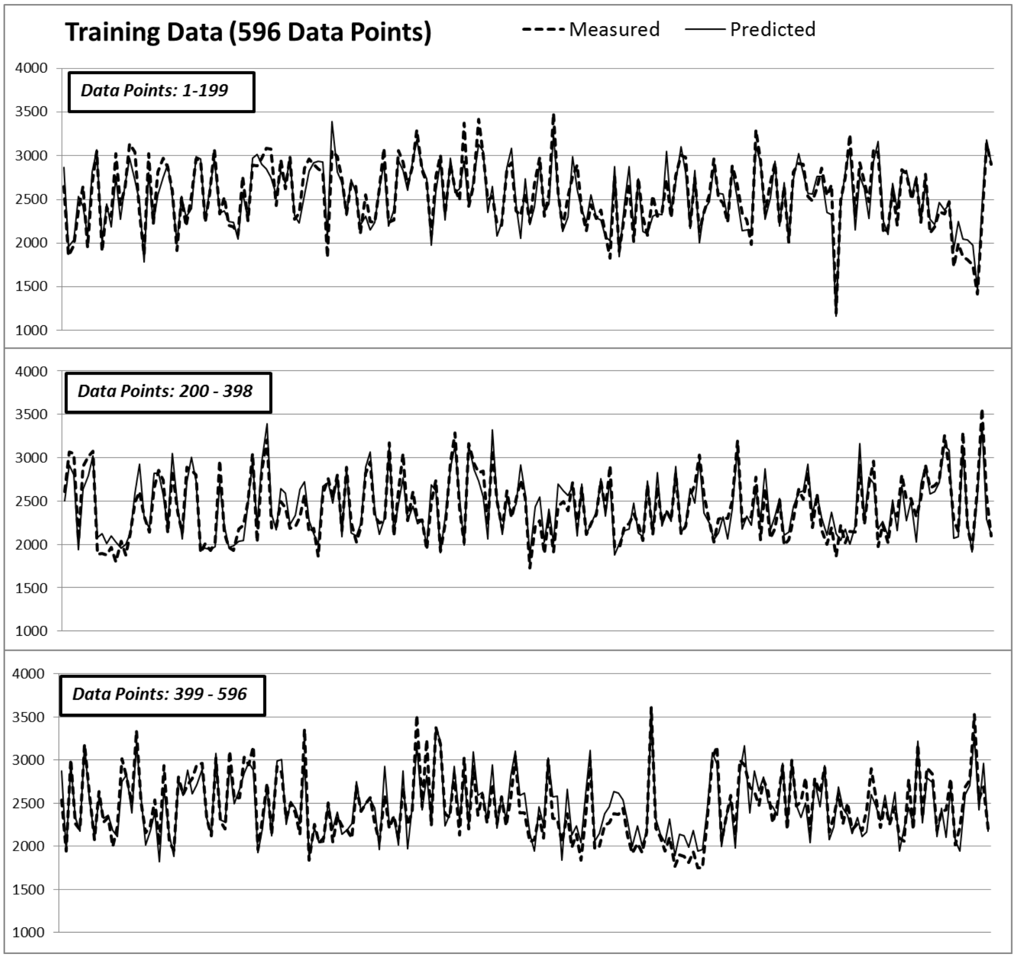

Figure 5.17: Plot of the Measured and Predicted BHP Values for Training Samples using the ANFIS model

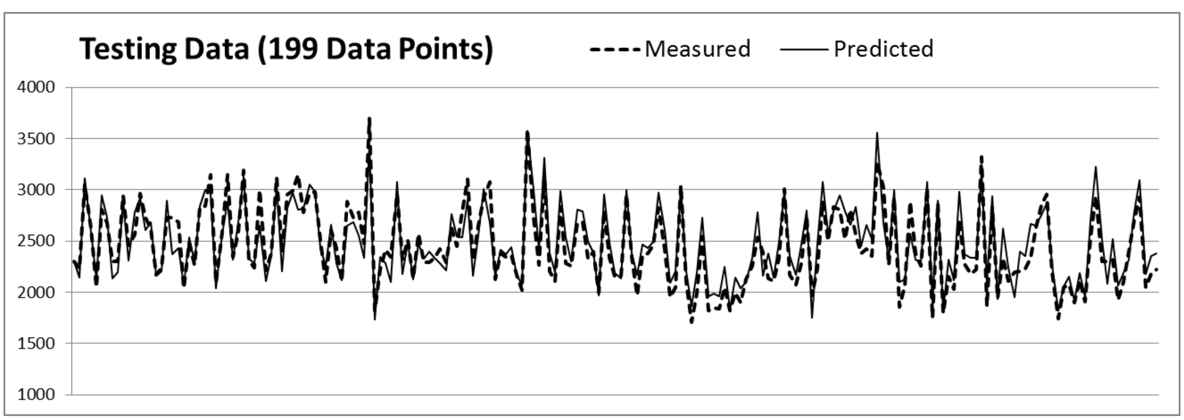

Figure 5.18: Plot of the Measured and Predicted BHP Values for Testing Samples using the ANFIS model

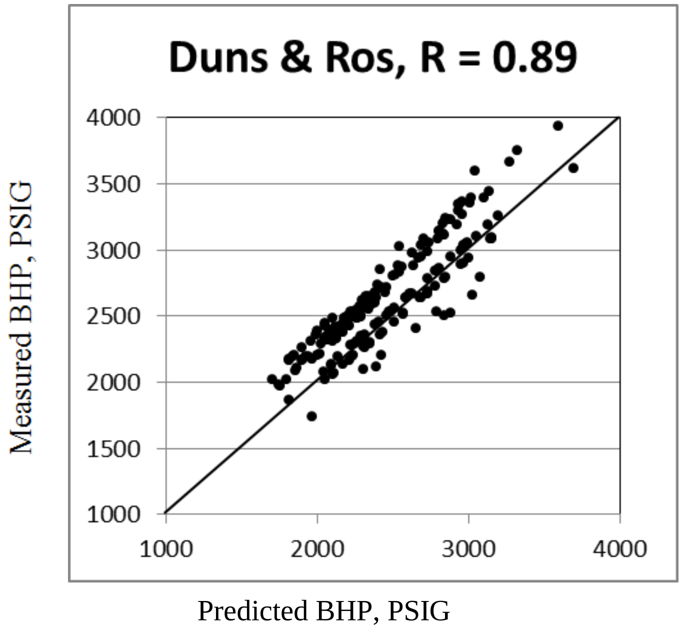

Figure 5.19: Cross Plot of Duns and Ros Model

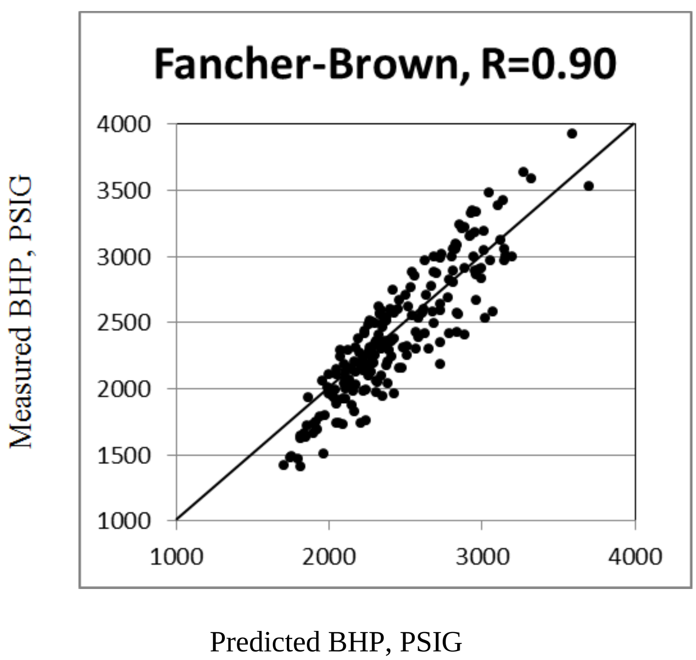

Figure 5.20: Cross Plot of Fancher and Brown Model

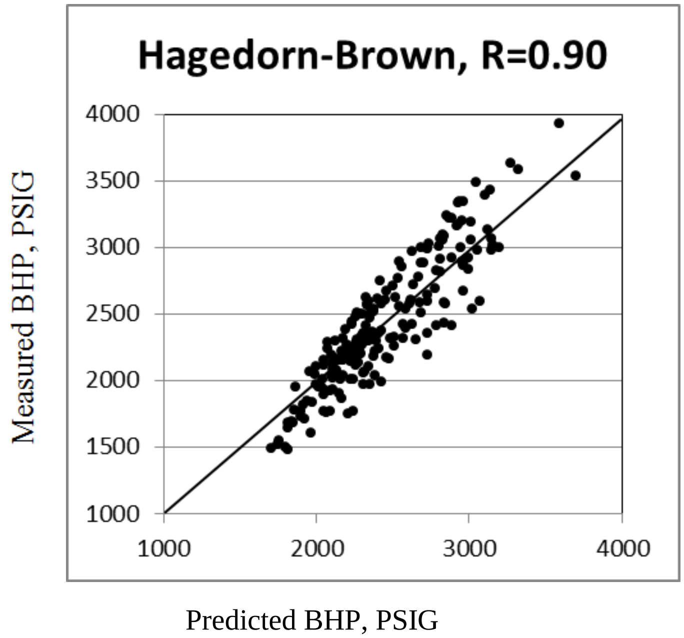

Figure 5.21: Cross Plot of Hagedorn and Brown Model

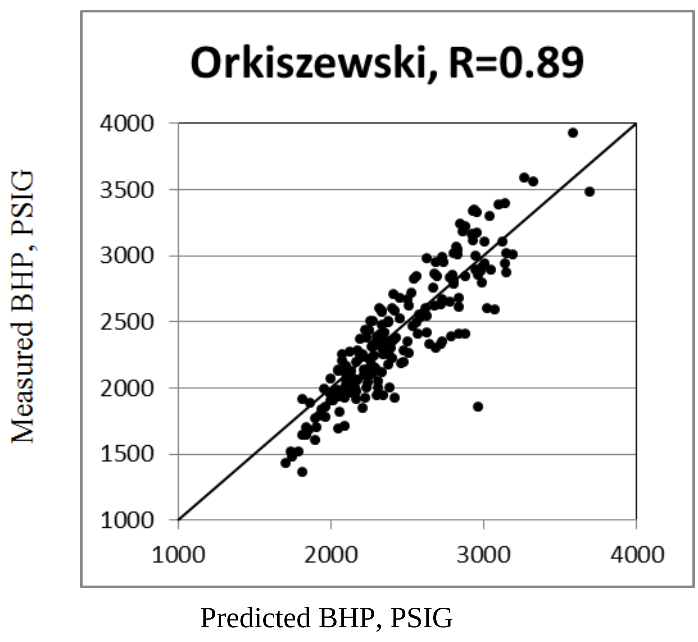

Figure 5.22: Cross Plot of Orkiszewski Model

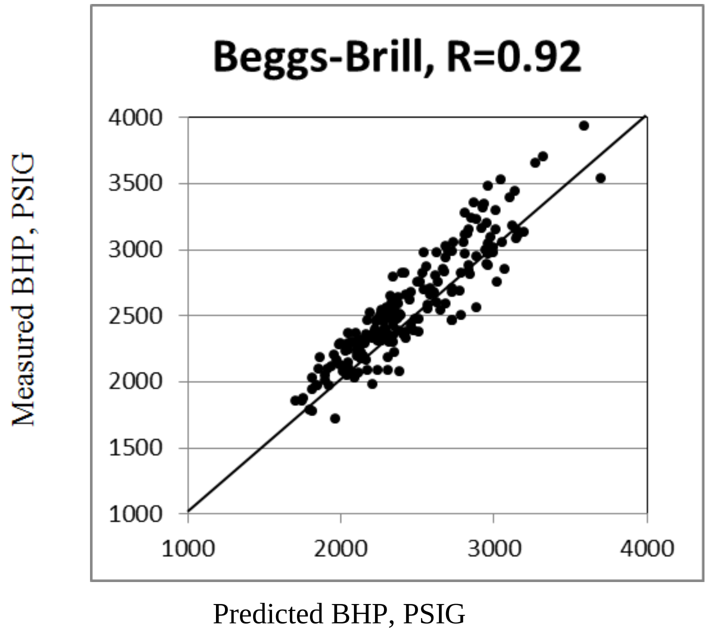

Figure 5.23: Cross Plot of Beggs and Brill Model

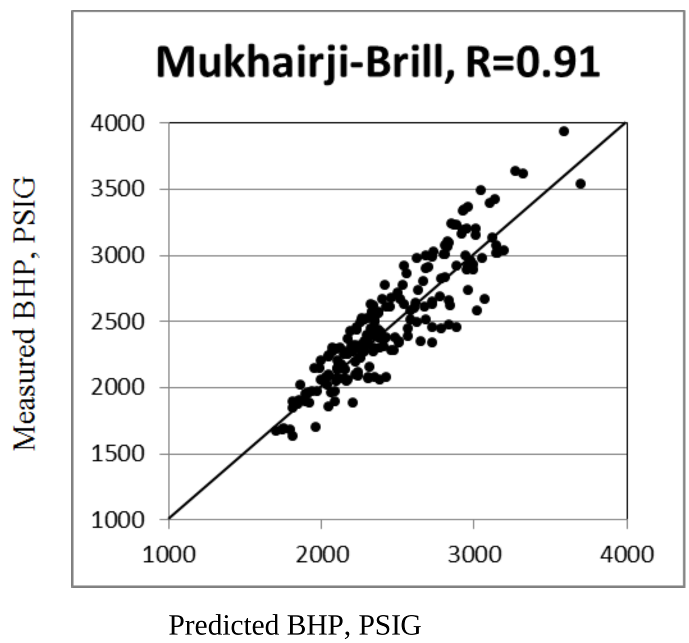

Figure 5.24: Cross Plot of Mukherjee and Brill Model

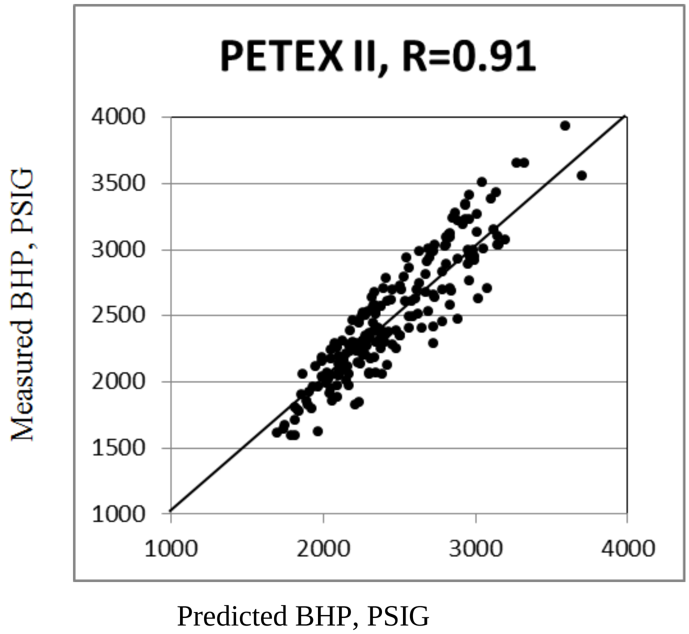

Figure 5.25: Cross Plot of Petroleum Experts II Model

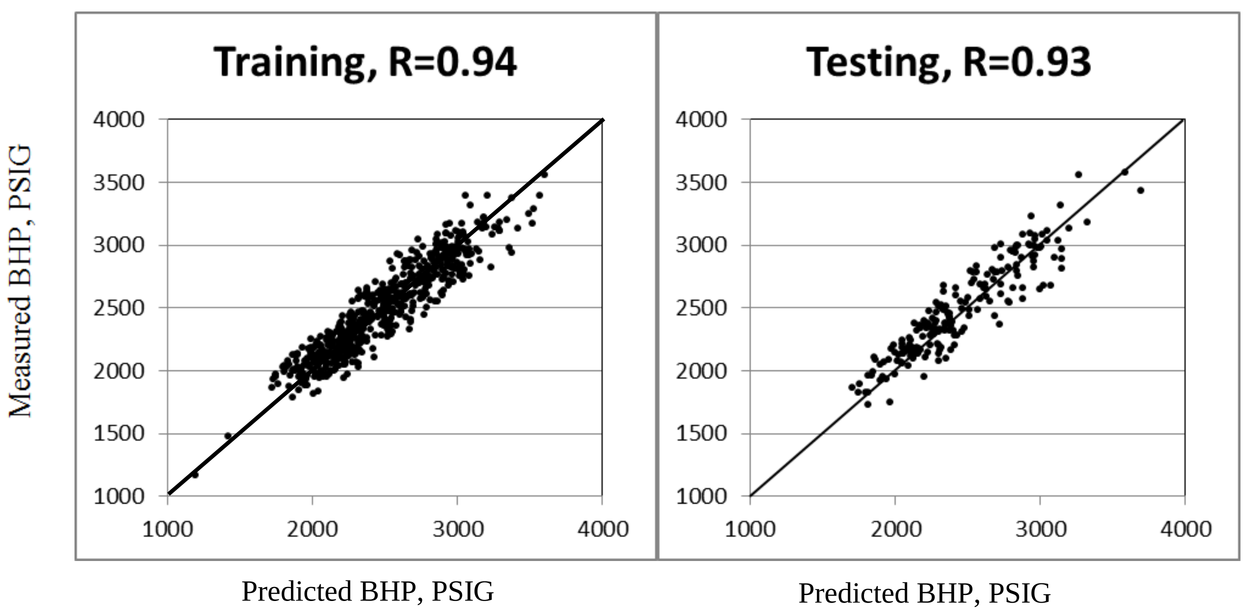

Figure 5.26: Cross Plot of ANFIS Model for Training and Testing Samples

Although these two models appear graphically similar in the cross-plot, there is a slight difference between the two that is difficult to capture graphically. The cross-plot for Orkiszewski model (Figure 5.22) provides a good representation of the results with a slight trend towards under-estimating the BHP for larger values. The cross plots for both Mukherjee-Brill (Figure 5.24) and Petroleum Experts II (Figure 5.25) are reasonably very good compared with the previously mentioned models with a correlation factor of 0.91 for both. However, the best empirical model that provided larger value of the correlation coefficient and better even distribution of the results above the below the 45^o straight line is Beggs and Brill model (Figure 5.23) with a correlation coefficient value of 0.92. Figure 5.26 demonstrates the cross-plots for the training and testing samples of the developed ANFIS model. The two plots indicate the excellent match between the measured and predicted BHP values and the even distribution above and below the 45^o straight line.

*5.7.2.2*Error Distributions Histogram

The histogram of error distribution and the normal distribution curve provide means for displaying the errors dispersal graphically to understand the performance of the model prediction results. The errors are said to be normally distributed with a mean around the 0%. Figures 5.27 and 5.28 display the ANFIS model error distributions histogram and the normal distribution curve applied for the training and testing data sets. Both plots indicate excellent behavior and normal distribution around the 0% error. Comparing that with the empirical correlations, we notice that the worse histogram distribution was for Duns and Ros model (Figure 5.29), which indicates a clear shift towards an average error of +7 with weak normal distribution of the errors. The rest of the empirical models provided reasonably better distribution histogram plots compared with Dun and Ros model.

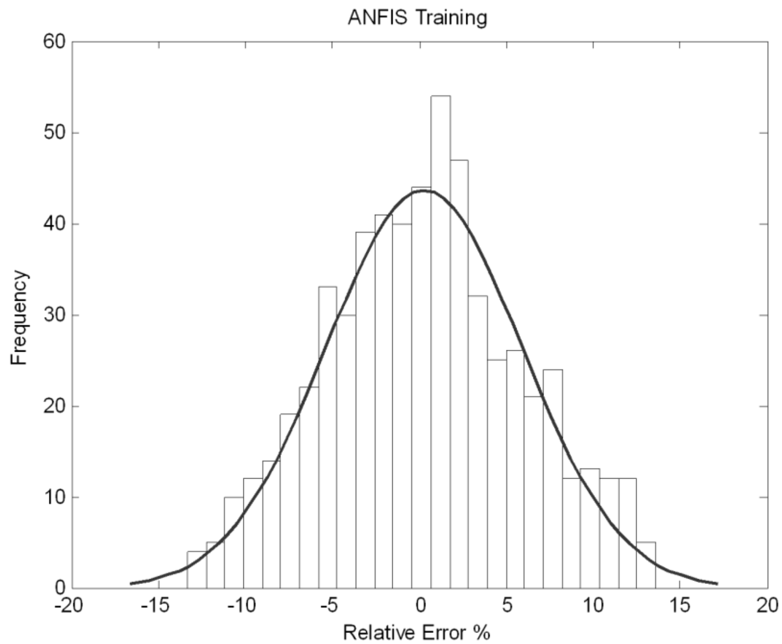

Figure 5.27: Histogram of Relative Error Distribution for the Developed ANFIS Model using the Training Sets Results

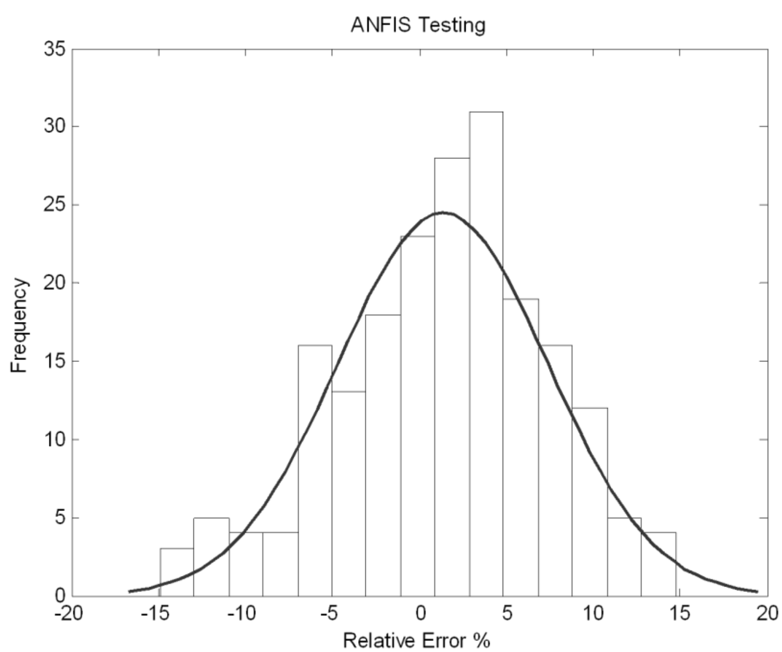

Figure 5.28: Histogram of Relative Error Distribution for the Developed ANFIS Model using the Testing Sets Results

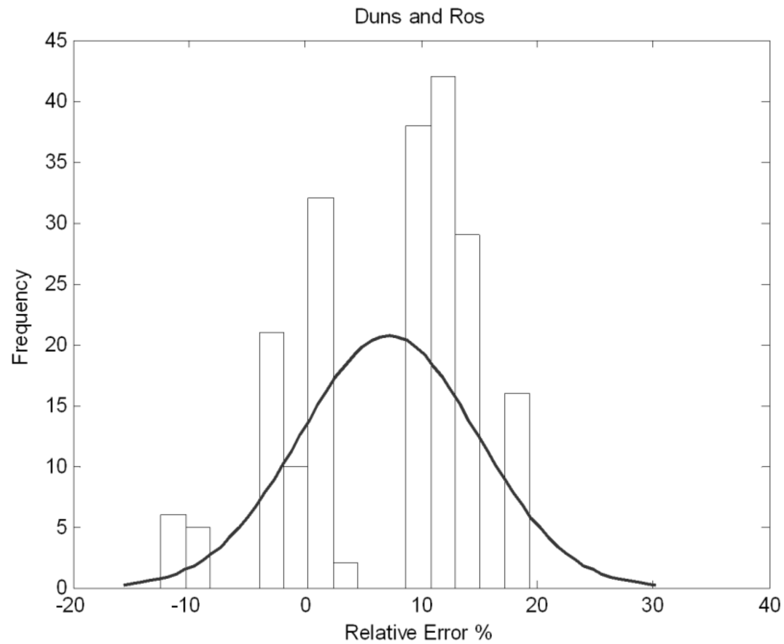

Figure 5.29: Histogram of Relative Error Distribution for Dun-Ros Model

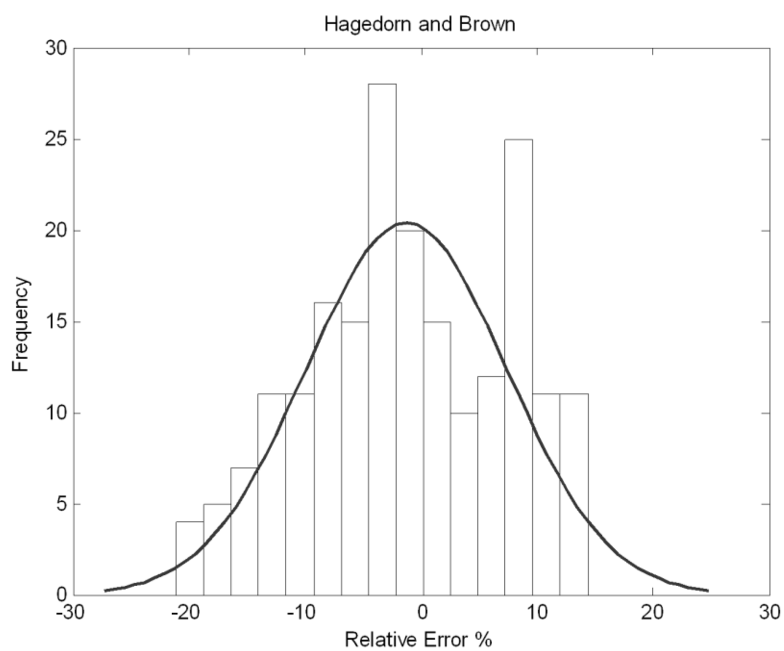

Figure 5.30: Histogram of Relative Error Distribution for Hagedorn-Brown Model

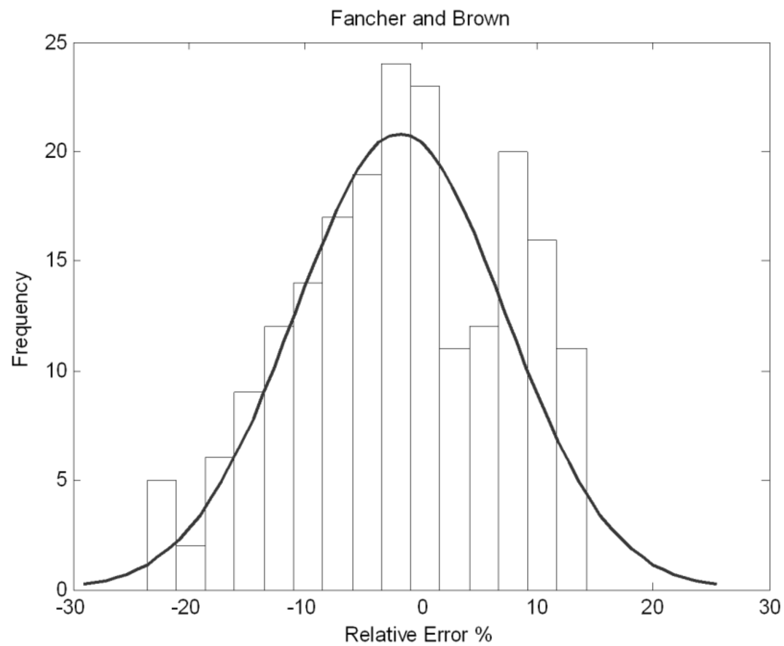

Figure 5.31: Histogram of Relative Error Distribution for Fancher-Brown Model

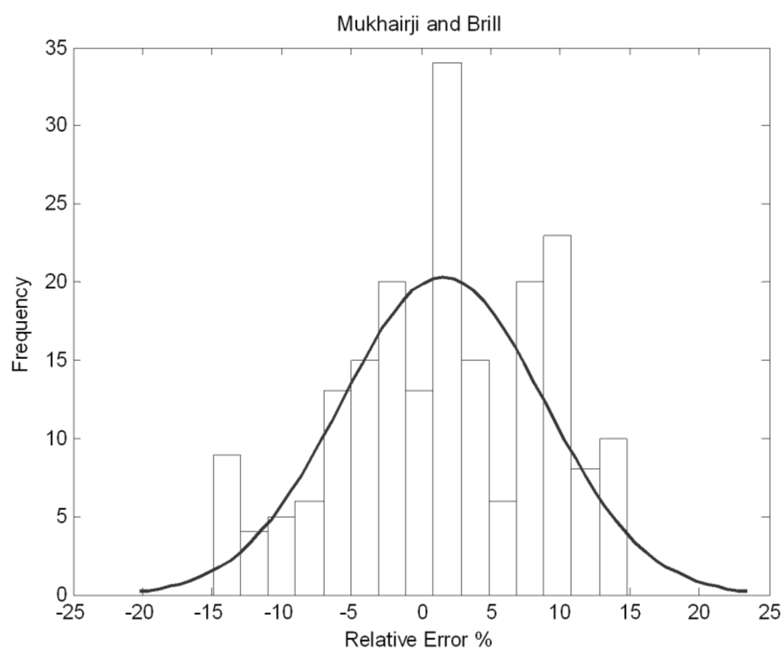

Figure 5.32: Histogram of Relative Error Distribution for Mukherjee-Brill Model

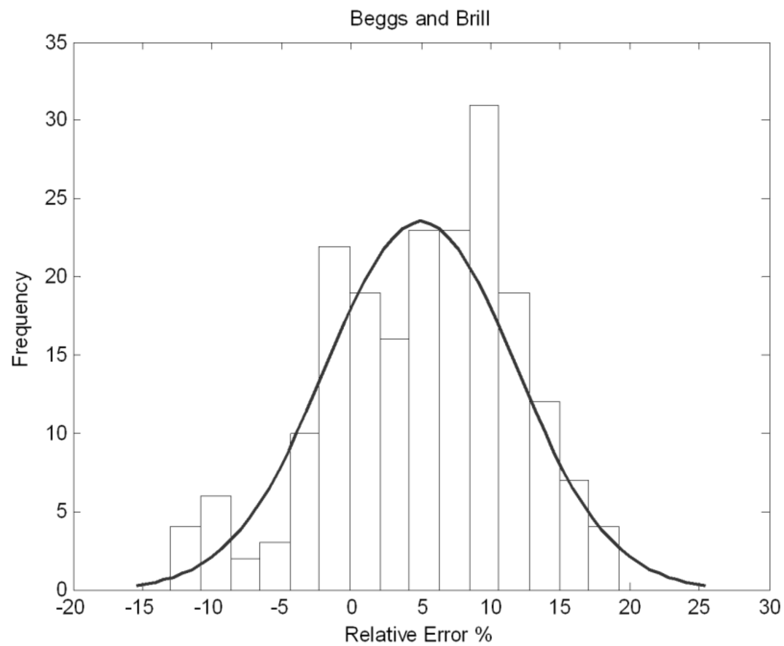

Figure 5.33: Histogram of Relative Error Distribution for Beggs-Brill Model

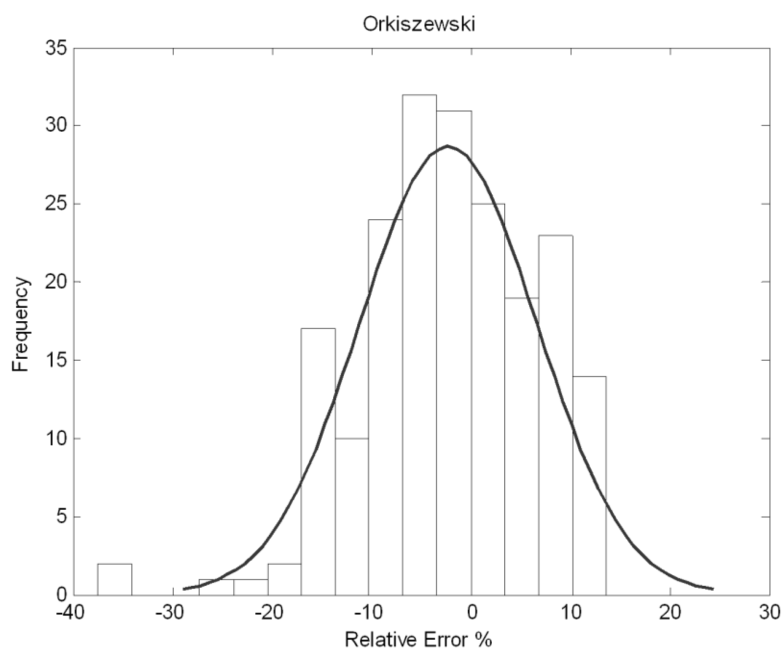

Figure 5.34: Histogram of Relative Error Distribution for Orkiszewski Model

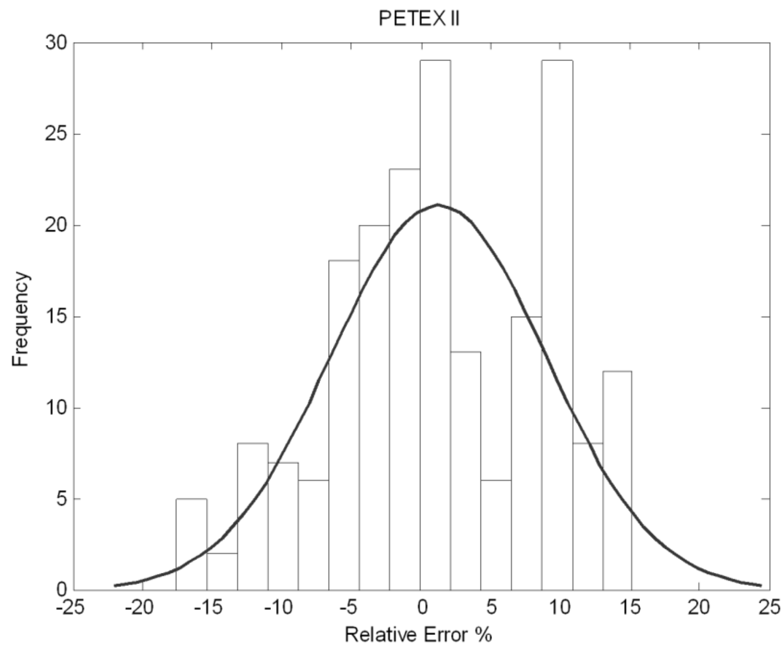

Figure 5.35: Histogram of Relative Error Distribution for Petroleum Experts II Model

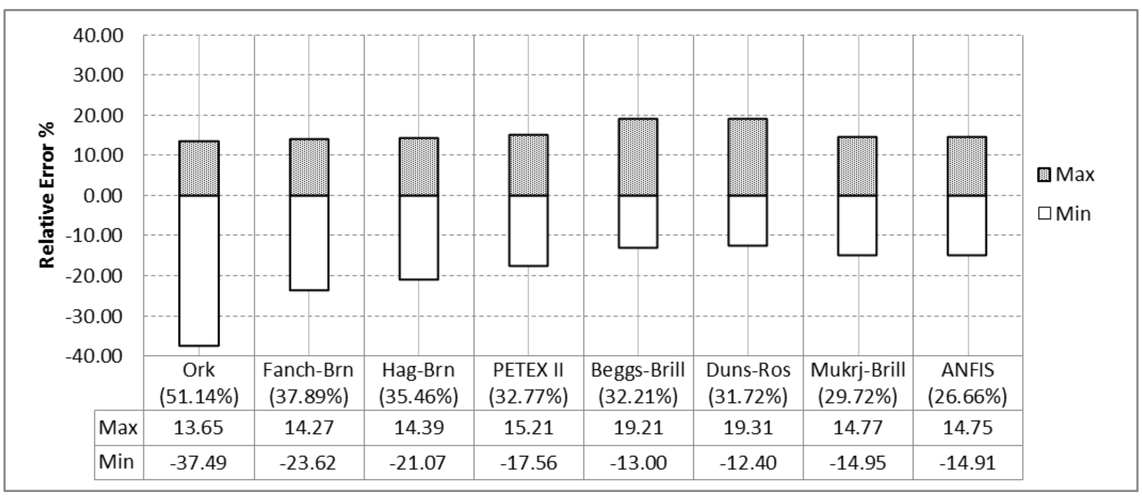

Figure 5.36: Relative Percent Error Ranges for the Empirical Correlations and ANFIS

*5.7.2.3*Relative Error Ranges

Finally, the relative error ranges were calculated and plotted in Figure 5.36for the empirical models and the developed ANFIS model. The ANFIS model relative error range was

26.66%, which is the lowest compared with all empirical models and the minimum and maximum values were (-14.91 and +14.75%) respectively. The best empirical model that provided excellent error range representation among the rest of the models is Mukherjee and Brill's. It has a very close range to the ANFIS model with a value of 29.72% (-14.95% to 14.77%). The worst empirical model when it comes the relative error range is Orkiszewski as it has a range of value 51.14% and the minimum value was -37.49%, which is deviating away from the maximum value of 13.65%. The rest of the empirical correlation relative error ranges can be viewed in Figure 5.31.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the results and discussions presented in this study, the following conclusions can be drawn:

1. Adaptive Neuro Fuzzy Inference System has been used successfully in developing a model for predicting flowing bottom-hole pressure in vertical wells
2. The developed model outperformed the best available empirical correlations.
3. The developed model achieved best lowest average absolute error (4.93%), the lowest maximum absolute error (14.91%), the best correlation coefficient (0.93), the lowest root mean square error (6.03%) and the lowest standard deviation of the errors (5.87)
4. A trend analysis showed that the developed model predicts the physical behavior

6.2 Recommendations

1. The developed model accuracy can be improved by adding new training data samples covering wider ranges and adding new combinations of variables to improve the ANFIS rules.
2. The new developed model can only be used within the ranges of the training data. Caution must be taken beyond these ranges.

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APPENDIX A

ANFIS MODEL DETAILS

Table A1: ANFIS Model Characteristics

Model Type	Sugeno
Number of Inputs	8
Number of Outputs	1
Number of Rules	5
Number of Membership Functions	5
Membership Function	Gaussian
And Method	Prod
Or Method	Probabilistic
Implication Method	Prod
Aggregation Method	Max
Defuzzification Method	Weighted Average
Number of Nodes	101
Number of Linear Parameters	45
Number of Non-Linear Parameters	80
Number of Training Data Pairs	596

Table A2: Input Data Cluster Centers and Range of Influence

	WHP	Qw	Qo	Qg	Depth	API	ID	Tres
Cluster Center 1	440	1772	4058	1554	6350	33	4	217
Cluster Center 2	300	1825	1846	4968	6448	33	4	217
Cluster Center 3	291	497	2754	358	5714	28	4	160
Cluster Center 4	180	6763	4604	2412	6840	33	4	217
Range of Influence (S)	309.3	2417.3	3709.6	3784	928.5	4.7	0.9	15.5

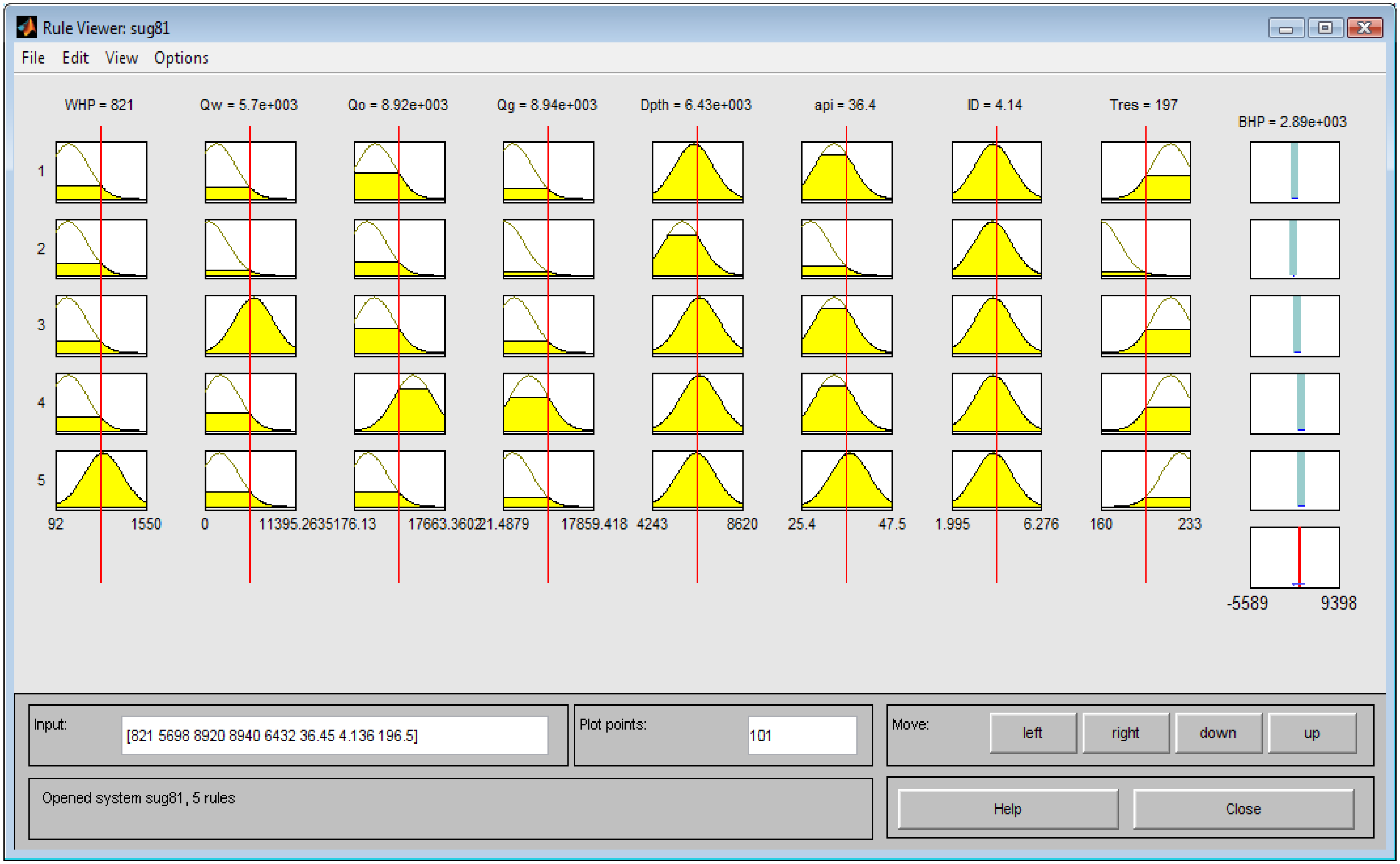

Figure A.1: Screenshot of the ANFIS Rule Viewer

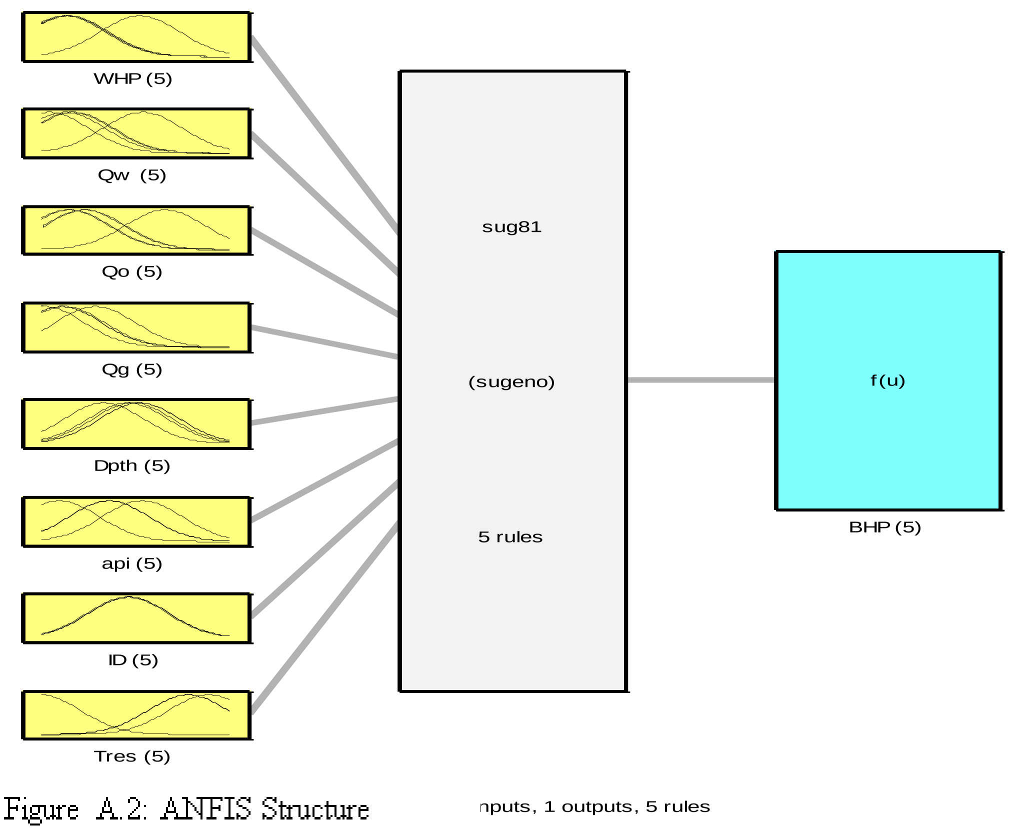

Figure A.2: ANFIS Structure

APPENDIX B

DATA AND NUMERIC RESULTS

APPENDIX B

Table B.1: Data Used for Training the ANFIS Model and the Predicted BHP

SN	WHP	Qw	Qo	Qg	Depth	API	ID	Tres	BHP	Pred BHP
1	670	3822	1848	248	6858	33.4	4	217	3234	3204.1
2	600	2420	824	1078	6567	31.7	3.958	200	2649	2866.7
3	340	140	5469	2620	6252	33.4	4	217	1851	1961.3
4	280	2245	6455	3118	6164	33.4	3.958	217	1975	2040.7
5	380	2758	3642	1344	6486	33.4	3.958	217	2383	2532.1
6	200	165	14790	7040	6584	37.3	3.958	225	2648	2423.6
7	225	1544	4218	1523	6135	33.4	3.958	217	1952	2077.5
8	390	2073	324	382	6811	31.7	2.992	200	2685	2818.7
9	1200	4	4106	3219	6846	38.3	4	209	3049	3071.2
10	220	806	7500	3750	6716	33.4	4	217	1906	2014.6
11	390	5521	6456	833	5944	33.4	4	217	2414	2447.3
12	210	746	4229	249	6026	27.6	3.958	160	2306	2182.7
13	295	3619	584	249	6808	33.4	4	217	3025	2759.0
14	460	1175	4315	1821	5998	33.4	4	217	2436	2276.8
15	280	6163	4178	2273	6542	33.4	4	217	2635	2668.9
16	850	396	1170	1043	6758	38.3	2.992	209	3135	2968.5
17	700	2102	6338	2580	6200	33.4	3.958	217	3039	2723.5
18	220	9481	4319	3170	5901	33.4	3.958	217	2344	2477.2
19	240	9	4438	1771	5664	31.7	4	200	1865	1786.7
20	300	7773	8091	5210	6683	37.3	3.958	225	3026	2806.7
21	220	3012	1391	771	5885	33.4	3.958	217	2222	2229.3
22	400	30	15094	7970	6889	33.4	3.958	217	2812	2555.6
23	580	1699	5017	2192	6530	37.3	3.958	225	2969	2758.7
24	400	10335	6552	5392	6583	37.3	6.276	225	2872	2899.7
25	250	329	16971	10454	6607	37.3	4	225	2599	2523.8
26	92	0	639	42	5146	26.2	3.958	160	1916	2004.2
27	270	2060	2314	1641	7025	31.7	2.992	200	2515	2538.5
28	340	126	3018	235	5687	28.1	4	160	2195	2299.3
29	220	3670	3730	1264	6394	33.4	4	217	2532	2397.0
30	1000	90	5910	3700	6535	37.3	4	225	2968	2986.2
31	900	719	2625	1299	6243	33.4	4	217	2944	2961.9
32	240	432	13083	5809	6310	33.4	3.958	217	2239	2259.4
33	240	2744	2165	983	6694	37.3	3.92	225	2580	2623.1
34	760	30	15170	7979	6717	37.3	3.958	225	3080	2966.1
35	225	3556	10612	5094	6248	33.4	4	217	2335	2347.6
36	300	1022	1434	610	6559	31.7	3.958	200	2531	2367.2
37	320	0	1929	253	6161	27.6	4	160	2206	2248.6
38	215	720	10187	5440	6759	33.4	3.958	217	2183	2235.2
39	400	1429	8927	4499	5533	33.4	3.958	217	2103	2043.5
40	230	1899	1256	417	6383	33.4	2.441	217	2761	2581.8

41	540	2628	2618	2508	5545	33.4	3.958	217	2258	2272.5
42	190	10380	4406	2481	6784	37.3	4	225	2891	2973.9
43	800	3984	916	2254	6312	38.3	4	209	2889	3014.6
44	1000	7	6593	4127	6386	37.3	4	225	2975	2906.3
45	305	5193	571	405	6742	33.4	4	217	3088	2853.8
46	220	5792	753	409	6629	33.4	3.958	217	3079	2750.1
47	270	5831	4582	3051	6410	33.4	4	217	2429	2556.8
48	620	3410	1190	547	5902	33.4	4	217	2953	2822.7
49	540	80	11357	6235	6824	37.3	3.958	225	2625	2682.4
50	1120	1380	5698	5886	6516	38.3	4	209	2989	2967.8
51	130	4311	4243	395	5588	27.6	4	160	2270	2317.5
52	330	1018	3410	396	5132	27.6	3.958	160	2341	2234.6
53	290	1678	3898	2077	6351	37.3	2.441	225	2862	2549.5
54	600	1043	3656	461	6150	33.4	2.992	217	2961	2828.1
55	680	502	15698	11711	6797	38.3	4	209	2905	2918.5
56	570	2764	11336	9727	6897	38.7	4	220	2853	2938.2
57	700	1019	3532	1685	6649.8	33.4	3.958	217	2818	2925.9
58	230	1225	13017	5832	6567	33.4	6.276	217	1837	2073.5
59	1120	0	2295	1494	8150	33.7	4	175	3059	3392.9
60	440	1903	2155	855	6995	33.4	3.958	217	2992	2816.4
61	1260	26	3724	3850	5676	38.7	4	220	2738	2693.6
62	750	122	6637	3883	5462	37.3	3.958	225	2337	2314.4
63	240	7549	7138	5032	6593	37.3	3.958	225	2682	2726.6
64	500	1384	2759	1363	6435	33.4	4	217	2659	2587.6
65	300	874	9789	5423	6375	33.4	3.958	217	2108	2200.8
66	450	46	7654	5763	6698	33.4	2.992	217	2553	2309.2
67	276	0	5890	560	5821	27.6	3.958	160	2250	2153.6
68	340	6	1414	83	6164	27.6	3.958	160	2243	2234.9
69	320	2508	1892	1143	6587	37.3	4	225	2622	2622.7
70	620	4232	4566	3173	6507	37.3	3.958	225	3085	2915.6
71	291	497	2754	358	5714	27.6	3.958	160	2235	2192.0
72	420	707	3154	1375	5964	33.4	2.992	217	2262	2377.4
73	920	501	2711	1206	6200	33.4	4	217	3057	2943.9
74	433	2031	1394	353	6520	33.4	2.992	217	2929	2833.7
75	290	674	16601	9977	6706	37.3	3.958	225	2669	2607.6
76	700	912	2609	1130	6523	33.4	3.958	217	2872	2910.8
77	550	5860	3715	1835	7064	33.4	3.958	217	3292	3180.0
78	640	262	16133	13261	6756	38.3	3.958	209	2836	2863.9
79	510	5790	3610	3783	6276	38.7	4	220	2696	2736.3
80	495	376	6862	3733	5758	33.4	4	217	2092	1974.4
81	510	2909	7298	4452	6624	37.3	3.958	225	2760	2597.3
82	260	9901	5594	3250	6663	37.3	3.958	225	3010	2925.7
83	290	2348	8728	4189	6498	33.4	3.958	217	2339	2261.0
84	285	8223	5235	3785	6845	37.3	3.958	225	2907	2975.6
85	440	3027	2538	1403	6334	33.4	4	217	2621	2582.8
86	390	5680	6353	4289	6293	37.3	4	225	2495	2623.2
87	450	4903	625	125	6561	33.4	3.958	217	3376	2937.7
88	175	5661	6257	2847	6447	33.4	4	217	2423	2431.1

89	260	3482	12344	7196	6753	37.3	3.958	225	2648	2698.2
90	850	2362	2198	413	6223	33.4	4	217	3418	3127.0
91	860	1883	2921	1972	6379	37.3	4	225	3007	3048.9
92	730	161	6260	4901	6126	33.4	4	217	2492	2352.7
93	630	1249	6277	4205	6758	37.3	3.958	225	2533	2651.0
94	260	6	5689	2583	6525	31.7	2.992	200	2224	2081.3
95	390	1156	3379	865	4885	28.1	3.958	160	2205	2230.1
96	740	1465	10258	6267	6595	37.3	3.958	225	2848	2869.6
97	990	238	2562	2175	6730	37.3	3.958	225	2921	3089.8
98	260	2472	16994	11250	6752	37.3	6.276	225	2373	2437.8
99	200	97	4731	1438	6612	31.7	3.958	200	2319	2057.3
100	490	5009	4737	5840	6891	38.3	3.958	209	2580	2732.7
101	200	1142	2256	792	6555	33.4	4	217	2242	2214.2
102	280	4506	1814	999	5975	33.4	3.958	217	2679	2410.3
103	570	7678	4766	6129	6781	38.3	4	209	2984	2932.6
104	300	1825	10846	4968	6448	33.4	3.958	217	2309	2363.8
105	250	1605	13395	6698	6693	33.4	3.958	217	2558	2452.3
106	1080	1833	1153	611	6571	31.7	4	200	3491	3246.6
107	390	1331	1891	1061	6772	33.4	3.958	217	2581	2566.4
108	580	937	4389	2717	5089	37.3	4	225	2177	2130.4
109	220	3065	2830	968	6146	33.4	3.958	217	2533	2299.1
110	960	47	9353	9353	6863	38.7	3.958	220	2766	2988.8
111	265	4623	1962	918	6908	31.7	3.958	200	2892	2614.7
112	205	318	1734	799	6214	33.4	1.995	217	2367	2379.0
113	342	0	6349	622	5625	27.6	4	160	2143	2234.9
114	610	500	3319	2323	6360	33.4	4	217	2438	2553.8
115	400	233	2220	313	5083	27.6	4	160	2284	2293.9
116	170	3646	7078	2980	6576.14	33.4	3.958	217	2378	2264.3
117	225	21	10727	4677	6113	33.4	3.958	217	2099	2071.6
118	747	204	3190	2871	4600	42.5	4	185	1827	2026.1
119	310	5935	12497	7336	6683	37.3	3.958	225	2774	2872.4
120	220	262	8468	1804	4770	25.4	3.958	160	1907	1842.5
121	230	81	2051	250	6322	35.3	2.441	233	2323	2461.3
122	580	5787	6713	5786	6645	38.7	3.958	220	2683	2879.0
123	425	145	3145	811	4688	25.4	4	160	2022	2122.3
124	245	5012	12095	9639	6587.1	37.3	3.958	225	2745	2739.5
125	250	61	12099	5178	6180	31	4	225	2301	2131.3
126	265	0	1870	168	5000	26.4	3.958	160	2092	2109.9
127	550	1347	5006	3504	6313	33.4	4	217	2546	2311.2
128	280	26	12869	5251	6666	33.4	4	217	2312	2336.2
129	180	2218	2097	1292	6085	33.4	2.441	217	2350	2326.3
130	480	2748	1692	1116	7296	33.4	4	217	2730	3048.4
131	220	1082	12617	4820	6623	33.4	3.958	217	2290	2351.0
132	570	2979	8221	6396	6746	38.3	3.958	209	2771	2704.3
133	730	3235	2950	1092	6325	37.3	4	225	3004	3100.3
134	540	1208	792	257	6532	33.4	3.958	217	2984	2809.2
135	365	0	2357	193	5126	26.4	3.958	160	2192	2172.2
136	225	9077	4331	2655	6676	33.4	3.958	217	2742	2833.1

137	230	6	6313	1799	6376	33.4	4	217	2130	2001.5
138	250	5606	8694	4895	6291	33.4	3.958	217	2351	2382.2
139	215	3219	1073	684	6570	33.4	3.958	217	2550	2479.0
140	420	2161	3162	1290	6454	37.3	2.441	225	2968	2875.1
141	500	390	1944	437	5957	33.4	2.992	217	2521	2567.3
142	260	2301	11817	6641	6617	37.3	3.958	225	2459	2560.8
143	195	4903	1897	1231	5847	33.4	3.958	217	2236	2280.6
144	1050	0	4655	3030	7032	33.7	4	175	2886	2845.5
145	250	3	3023	1584	6565	37.3	1.995	225	2693	2542.8
146	560	690	6143	3778	6003	33.4	4	217	2348	2144.0
147	310	931	3031	982	5925	33.4	3.958	217	2263	2148.4
148	380	45	11110	5066	5772	33.4	4	217	1990	2148.9
149	460	6734	5248	2913	6964	37.3	3.958	225	3293	3109.6
150	250	6909	2491	2371	6929	33.4	3.958	217	2945	2930.1
151	280	2878	8822	3502	6312	33.4	3.958	217	2348	2276.2
152	270	2369	2068	759	6767	33.4	3.958	217	2696	2515.1
153	880	578	8182	3019	6419	37.3	3.958	225	2923	2938.6
154	225	2233	5388	2861	6957	33.4	3.958	217	2215	2199.2
155	320	3064	11809	3968	6661	37.3	3.958	225	2649	2696.5
156	360	25	4135	2072	6145	31.7	4	200	2010	2009.1
157	350	1039	4043	732	6937	33.4	2.992	217	2814	2724.9
158	470	6855	3270	3754	6613	37.3	3.958	225	2915	3026.1
159	430	3203	930	473	6562	33.4	3.958	217	2902	2798.5
160	320	950	13447	7517	6643	37.3	3.958	225	2538	2569.8
161	240	6199	3930	2193	6380	33.4	4	217	2481	2565.6
162	820	29	5867	3860	6486	37.3	4	225	2631	2762.3
163	420	5756	8181	4639	6588	37.3	4	225	2863	2759.2
164	230	2130	800	438	6378	33.4	3.958	217	2544	2353.7
165	390	52	8598	1840	6601	33.4	4	217	2670	2324.2
166	715	513	2909	17859	4900	42.5	4	185	1198	1163.7
167	600	13	6366	3018	6606	31.7	4	200	2492	2432.5
168	690	3658	9313	5951	6226	37.3	4	225	2758	2816.2
169	780	6797	5045	3102	6501	37.3	6.276	225	3240	3083.6
170	145	700	2700	394	5060	27.6	4	160	2297	2148.9
171	580	3730	7540	3491	6782	33.4	3.958	217	2919	2770.2
172	280	6291	2009	818	6270	33.4	4	217	2701	2619.4
173	210	1842	793	309	6269	33.4	4	217	2478	2282.5
174	670	3455	9437	6134	6811	38.3	4	209	3078	2934.0
175	360	4817	2416	283	7451	33.4	3.958	217	3035	3168.3
176	240	2183	9680	5140	6437	33.4	3.958	217	2115	2251.6
177	310	220	7930	3862	6684	33.4	3.958	217	2167	2098.1
178	700	694	9082	5268	6490	37.3	3.958	225	2624	2684.9
179	1040	1429	5035	7276	5226	37.3	4	220	2200	2388.6
180	240	8451	5970	4382	6578	37.3	3.958	225	2843	2797.2
181	200	9298	3910	2064	6693	33.4	4	217	2795	2834.9
182	220	4956	2668	1414	6435	33.4	3.958	217	2498	2535.9
183	980	67	9472	6242	6223	33.4	4	217	2736	2762.4
184	350	0	4912	383	5787	28.1	3.958	160	2238	2243.8

185	820	1645	11727	6004	6399	37.3	6.276	225	2789	2694.0
186	180	2896	4806	476	5860	27.6	4	160	2117	2278.2
187	410	0	2718	457	4948	26.4	4	160	2190	2209.7
188	275	3707	6534	4071	6712	37.3	4	225	2358	2461.8
189	450	2118	6355	3902	6425	37.3	3.958	225	2334	2378.3
190	270	153	16848	9283	6214	37.3	3.958	225	2477	2447.4
191	230	1219	5265	2643	6348	33.4	3.958	217	1732	1936.2
192	210	1986	2655	1232	6646	31.7	4	200	1996	2250.7
193	230	327	7657	3178	6859	31.7	3.958	200	1845	2043.2
194	180	1065	5200	2226	6776	33.4	3.958	217	1811	2042.0
195	225	1390	5073	2379	6331	33.4	4	217	1751	1974.4
196	270	1083	6600	2844	5422	33.4	6.276	217	1421	1474.1
197	250	1829	11426	6410	6778	33.4	3.958	217	2262	2420.1
198	600	4448	1730	1114	6874	33.4	3.958	217	3141	3181.6
199	790	633	11785	648	6224	37.3	4	225	2903	2921.8
200	440	4179	1816	1778	6834	33.4	3.958	217	2537	2870.8
201	290	80	7900	4005	6442	31.7	4	200	1941	1933.4
202	240	6182	748	555	6832	37.3	4	225	3006	2955.1
203	580	42	4658	1779	5841	33.4	4	217	2266	2329.4
204	230	1022	1488	731	6298	33.4	4	217	2191	2170.5
205	750	2791	1383	524	6509	33.4	4	217	3180	3169.8
206	205	4970	926	535	6407	33.4	4	217	2646	2578.2
207	293	47	5164	537	6050	26.4	3.958	160	2079	2105.0
208	1030	175	3064	199	5071	37.3	4	225	2634	2570.4
209	295	13	12727	5015	6532	33.4	3.958	217	2282	2320.2
210	120	5006	939	82	5006	27.6	4	160	2336	2361.7
211	230	1859	9013	4669	6494	33.4	3.958	217	1996	2178.9
212	340	1628	6762	3483	6581	31.7	4	200	2230	2108.0
213	800	536	8106	4434	6429	37.3	3.958	225	3016	2753.0
214	550	259	15941	12163	6816	38.7	4	220	2800	2829.0
215	250	28	13833	3140	6293	37.3	3.958	225	2495	2385.7
216	730	3505	1715	1216	6606	33.4	4	217	3342	3195.0
217	500	1022	8618	4344	6778	37.3	3.958	225	2510	2569.8
218	220	182	6078	2924	6508	31.7	2.992	200	2159	2011.6
219	495	844	5746	2896	6064	33.4	4	217	2234	2173.5
220	370	2700	7012	1262	6110	31.7	3.958	200	2539	2395.9
221	195	1095	6155	3508	6388	33.4	3.958	217	2012	1820.0
222	320	1611	1954	344	6613	37.3	4	225	2938	2672.2
223	260	13	12893	6240	5871	33.4	4	217	2047	2132.0
224	290	7	6593	3191	6403	31.7	4	200	1950	1882.7
225	420	6664	2047	1101	6273	33.4	4	217	2798	2767.3
226	480	2789	7280	976	6054	33.4	4	217	2601	2592.1
227	760	518	4883	2461	6570	37.3	3.958	225	2714	2878.1
228	230	2452	745	107	6459	33.4	2.992	217	2788	2605.7
229	290	4288	3712	3203	6881	37.3	4	225	2940	2711.1
230	240	8124	4690	3452	6729	37.3	3.958	225	2962	2889.1
231	349	1064	1664	158	6223	27.6	4	160	2325	2327.2
232	190	2678	8344	4013	6434	33.4	4	217	2118	2140.9

233	660	3121	479	1520	6656	38.3	2.992	209	3026	3076.0
234	210	3604	3984	1801	6340	33.4	3.958	217	2289	2303.4
235	415	34	5624	731	5838	35.3	4	233	2202	2280.5
236	600	1479	772	49	6541	33.4	4	217	3100	2928.5
237	400	1466	5198	1429	6678	33.4	4	217	2557	2491.4
238	250	7857	4878	2614	6429	33.4	3.958	217	2562	2658.3
239	225	7665	2735	1939	6742	33.4	4	217	3029	2842.6
240	700	1070	720	515	6565	33.4	3.958	217	2941	2971.8
241	550	1082	968	613	6800	33.4	3.958	217	3155	2880.5
242	320	65	7134	2575	5944	33.4	4	217	1960	1930.4
243	110	1993	2526	248	5750	27.6	4	160	2326	2211.4
244	880	412	2936	2508	6223	38.1	4	207	2733	2694.3
245	210	2496	8037	3416	6341	33.4	4	217	2141	2123.5
246	940	142	11693	6373	6472	37.3	3.958	225	2926	2987.9
247	1000	13	3284	1419	6350	33.4	4	217	2853	3006.8
248	260	1688	1602	107	4946	27.6	3.958	160	2312	2250.8
249	200	2719	2180	1049	6656	33.4	2.992	217	2497	2521.8
250	255	4311	3020	1386	6251	33.4	3.958	217	2385	2435.4
251	300	1833	9344	4289	6462	33.4	4	217	2136	2266.1
252	640	1454	1550	419	6603	33.4	3.958	217	3358	2974.4
253	260	240	6086	2191	5925	33.4	4	217	1841	1872.1
254	220	1511	3964	1708	6788	33.4	3.958	217	2251	2207.6
255	300	103	11341	5058	5550	33.4	4	217	2039	2038.7
256	190	2698	4168	2613	6525	31.7	4	200	2094	2052.5
257	250	3916	3688	1682	6656	33.4	4	217	2498	2511.7
258	225	2283	10544	4766	6022	33.4	4	217	2051	2201.4
259	440	1816	3542	1325	6054	33.4	4	217	2344	2395.6
260	245	2936	6384	3633	6715	31.7	3.958	200	2235	2134.1
261	230	2422	5029	2419	6643	33.4	3.958	217	2185	2189.8
262	340	861	10032	5217	6394	33.4	3.958	217	2098	2262.2
263	1050	299	3388	1843	5570	33.4	4	217	2698	2749.2
264	450	21	2268	229	6026	33.4	3.958	217	2408	2408.0
265	230	4147	1694	960	6109	33.4	2.992	217	2489	2492.9
266	250	2276	11110	5900	6729	37.3	3.958	225	2560	2548.5
267	320	1948	1693	907	6076	33.4	2.992	217	2258	2443.1
268	290	23	7489	3565	6583	31.7	4	200	2056	1960.3
269	720	558	2379	2025	6775	37.3	4	225	2590	2927.8
270	250	2075	8844	3600	6538	33.4	3.958	217	2211	2242.0
271	330	2036	3436	268	4912	37.3	4	225	2352	2338.1
272	230	538	5379	2345	6719	33.4	4	217	2095	2017.1
273	690	939	2321	1068	6449	33.4	3.958	217	2674	2875.5
274	350	15	7600	980	6170	33.4	6.276	217	2241	1974.5
275	240	4902	4011	1785	6332	33.4	4	217	2405	2460.1
276	680	2623	3577	644	6744	33.4	3.958	217	3522	3168.8
277	225	6828	7457	3274	6530	33.4	6.276	217	2456	2420.8
278	950	1910	5729	10840	6979	38.3	4	209	3236	2818.0
279	240	5641	6412	3488	6033	33.4	3.958	217	2240	2291.1
280	1120	2030	2243	357	6481	33.4	4	217	3374	3374.2

281	1170	426	4200	357	6465	37.3	4	225	3181	3219.1
282	320	3849	6306	3090	6380	31.7	3.958	200	2375	2235.6
283	450	20	4991	654	6046	33.4	4	217	2332	2368.8
284	950	84	16739	2628	6776	37.3	6.276	225	2838	2925.3
285	650	40	3911	1877	5512	33.4	4	217	2128	2301.4
286	780	285	3203	1794	6160	33.4	2.992	217	3027	2826.9
287	540	1018	5467	2515	5830	33.4	4	217	2202	2238.2
288	840	3189	686	1520	6362	38.7	4	220	2926	3095.9
289	230	4220	3880	1932	6849	33.4	4	217	2360	2590.2
290	435	2498	1751	756	6328	33.4	4	217	2597	2621.4
291	235	42	3793	1547	6595	31.7	2.441	200	2271	2296.6
292	700	1683	2323	1445	6453	37.3	3.958	225	2718	2941.9
293	240	0	1150	135	5556	27.6	4	160	2266	2207.2
294	345	3956	5160	2585	6773	33.4	3.958	217	2572	2578.9
295	220	4097	7316	3716	6515	33.4	3.958	217	2234	2305.1
296	580	1087	2196	1272	6581	37.3	3.958	225	2555	2814.7
297	950	2054	2746	1329	6548	38.3	4	209	3041	3099.1
298	410	1706	1594	558	6200	31.7	2.992	200	2389	2593.2
299	240	2797	1154	345	6385	37.3	3.958	225	2387	2612.8
300	200	2435	5549	2908	6790	33.4	3.958	217	2049	2146.9
301	425	125	6475	3179	6616	31.7	6.276	200	2078	1947.6
302	430	1402	5439	1985	6688	33.4	3.958	217	2349	2456.2
303	348	749	5387	1848	6555	33.4	4	217	2098	2241.4
304	640	6087	2609	2335	6816	38.3	4	209	3007	3022.8
305	260	5143	2499	1234	6376	33.4	4	217	2322	2569.4
306	270	4513	2495	1285	6493	33.4	3.958	217	2319	2581.7
307	200	565	6675	2383	5888	33.4	3.958	217	2039	1837.1
308	550	241	4315	1765	6595	31.7	2.992	200	2379	2658.3
309	245	69	8559	916	6012	33.4	4	217	1989	2128.8
310	250	1198	719	167	5658	31.7	2.992	200	2140	2239.2
311	360	12	4048	1688	5996	33.4	3.958	217	1836	2043.1
312	610	695	3705	1482	6290	31.7	3.958	200	2337	2594.4
313	680	1745	603	522	6812	37.3	3.958	225	2990	3110.2
314	320	1953	5023	2511	6124	31.7	4	200	1968	2056.5
315	200	3160	5544	2201	6173	33.4	3.958	217	1995	2151.5
316	320	2081	4421	1998	6804	33.4	3.958	217	2249	2376.1
317	440	1772	4058	1554	6350	33.4	3.958	217	2273	2460.2
318	260	4544	1115	827	6517	33.4	3.958	217	2374	2634.9
319	650	4007	6483	3241	5995	33.4	4	217	2367	2612.2
320	280	3312	1320	665	6468	33.4	3.958	217	2441	2536.3
321	440	1353	6847	2143	6134	33.4	4	217	2125	2286.4
322	998	466	2276	2208	4750	42.5	4	185	1920	1992.8
323	170	2944	4379	2128	6651	33.4	3.958	217	2035	2234.2
324	230	371	15080	8143	6723	31.7	6.276	200	1929	2002.8
325	180	2748	3826	1990	6626	31.7	4	200	2166	2168.5
326	1550	235	4373	669	6788	33.4	4	217	3604	3555.6
327	210	954	3288	1335	6689	31.7	2.992	200	2213	2313.5
328	160	98	10817	714	4983	27.6	4	160	2103	2141.7

329	215	399	4585	2095	6254	31.7	2.992	200	1944	2038.3
330	410	2059	5018	1882	6121	33.4	4	217	2107	2311.1
331	230	409	5603	2605	6449	31.7	4	200	1767	1892.7
332	400	57	4343	2267	6423	31.7	3.958	200	1900	2136.8
333	190	1939	3418	1883	6602	33.4	3.958	217	1885	2123.5
334	260	2854	4408	2032	5608	31.7	4	200	1810	1985.3
335	200	819	2296	790	6557	33.4	4	217	1933	2183.9
336	220	259	5034	1953	6367	33.4	3.958	217	1748	1946.2
337	185	586	7336	2964	6640	31.7	3.958	200	1753	1959.8
338	280	6130	2348	1649	5859	33.4	3.958	217	2283	2408.2
339	820	1448	743	999	6962	38.3	4	209	3020	3087.3
340	300	1625	966	365	7033	33.4	1.995	217	3153	2949.6
341	220	2301	3645	1903	5889	33.4	4	217	2059	1995.6
342	340	475	1746	461	6312	33.4	3.958	217	2335	2344.7
343	225	1893	14151	9170	6466	37.3	3.958	225	2587	2528.4
344	975	391	4493	4143	4700	42.5	3.958	185	2122	1974.9
345	550	1253	2442	2086	6639	38.3	2.441	209	2997	2858.7
346	810	3436	11246	1844	6463	37.3	4	225	2946	3165.1
347	240	66	16488	8706	6629	33.4	3.958	217	2684	2384.5
348	560	3484	4208	2503	6593	37.3	3.958	225	2636	2869.5
349	350	3746	1820	1578	6672	33.4	4	217	2472	2642.1
350	550	2366	1063	461	6275	33.4	3.958	217	2763	2805.7
351	210	2922	938	315	6644	33.4	4	217	2634	2510.5
352	310	1455	1545	593	6149	33.4	2.992	217	2268	2458.5
353	200	1089	2718	1163	6386	33.4	2.441	217	2476	2363.3
354	370	8187	8024	3547	6859	37.3	4	225	2937	2957.3
355	383	0	836	145	5858	26.4	4	160	2192	2232.7
356	1020	673	2887	1969	6041	33.4	2.992	217	2994	2990.6
357	250	3623	1729	832	6369	33.4	3.958	217	2466	2473.8
358	800	672	6556	5009	5628	37.6	4	196	2523	2332.6
359	450	27	2674	289	6329	33.4	4	217	2789	2502.6
360	320	1112	6890	3286	6453	31.7	3.958	200	2166	2039.8
361	380	9222	9637	7363	6337	37.3	3.958	225	2783	2754.7
362	260	4112	7536	3791	6486	37.3	4	225	2612	2460.1
363	680	452	853	298	6642	33.4	4	217	2920	2934.4
364	190	1734	6008	2481	6622	33.4	3.958	217	2169	2077.7
365	245	174	1002	359	6442	33.4	3.958	217	2340	2225.2
366	250	7528	3272	1594	6433	33.4	3.958	217	2611	2690.1
367	195	16	2032	175	6094	35.3	1.995	233	2260	2438.0
368	290	4047	3297	1039	6267	31.7	4	200	2502	2362.3
369	135	32	2080	189	6399	27.6	4	160	2190	2148.4
370	320	1242	10589	4680	6493	33.4	3.958	217	2259	2336.8
371	310	1311	3851	2268	6483	31.7	4	200	2184	2109.4
372	210	3708	3354	1452	6675	31.7	6.276	200	2421	2169.0
373	230	4769	10614	5424	6896	33.4	4	217	2895	2598.4
374	190	3797	7051	4146	6863	37.3	3.958	225	2571	2465.6
375	200	4537	2214	1050	5923	33.4	4	217	2221	2297.9
376	280	6185	7468	3809	6573	33.4	3.958	217	2492	2587.1

377	250	2811	9149	3605	6297	33.4	3.958	217	2251	2258.9
378	650	1037	2095	1067	5899	33.4	3.958	217	2456	2620.5
379	1033	500	4500	4640	4660	42.5	4	185	2098	1946.3
380	360	1261	5339	2435	6599	31.7	4	200	2058	2205.8
381	495	3014	6174	2877	6296	33.4	4	217	2776	2448.8
382	420	41	3099	381	5917	27.6	3.958	160	2190	2251.3
383	780	4218	5801	1265	6526	33.4	3.958	217	3185	3220.6
384	225	865	3234	58	6500	27.6	4	160	2336	2270.4
385	1100	19	4673	4281	5992	37.3	4	225	2909	2793.6
386	180	6763	4604	2412	6840	33.4	4	217	2833	2742.3
387	460	1179	7821	3410	5824	33.4	4	217	2180	2114.8
388	300	2003	11715	5190	6541	33.4	4	217	2402	2434.8
389	400	4121	7619	3551	5985	33.4	6.276	217	2425	2101.2
390	740	4823	4277	3866	5905	38.1	4	207	2788	2675.9
391	120	0	2043	282	5249	27.6	3.958	160	2011	2067.2
392	180	848	5833	2677	6027	33.4	2.992	217	2220	1945.7
393	280	3852	3335	1614	6438	37.3	4	225	2686	2597.6
394	390	1282	14944	9056	6693	37.3	3.958	225	2765	2705.9
395	900	182	1118	807	8620	47.5	2.992	189	3524	3289.1
396	590	1143	11277	5943	6392	37.3	6.276	225	2542	2418.4
397	600	2480	15620	12481	6458	38.7	4	220	2691	2956.7
398	145	666	1120	166	6173	27.6	4	160	2204	2178.1
399	250	3567	17663	11587	6645	37.3	6.276	225	2612	2503.9
400	700	1458	9423	4881	7038	37.3	3.958	225	3065	2921.2
401	560	1189	723	310	6700	33.4	6.276	217	3048	2802.7
402	330	331	7022	3223	6240	31.7	4	200	2050	1936.8
403	320	854	176	21	6350	33.4	2.441	217	2903	2636.2
404	320	5495	9437	5813	6913	37.3	3.958	225	3015	2796.0
405	305	9563	3700	1443	6712	37.3	3.958	225	3076	3019.9
406	240	2484	5328	2461	6195	33.4	3.958	217	1889	2078.0
407	470	16	5284	2198	6017	31.7	4	200	1899	2127.4
408	1028	275	3658	2977	4800	42.5	3.958	185	1874	2008.6
409	280	782	6457	2551	6696	31.7	3.958	200	1965	2099.7
410	196	1917	4955	1823	6093	33.4	4	217	1796	2030.1
411	205	335	4260	1286	6013	31.7	3.958	200	2038	1957.9
412	180	3018	4781	2271	6580	33.4	6.276	217	1880	1999.3
413	300	2353	4388	2111	6058	33.4	3.958	217	2131	2129.3
414	532	3084	10503	3812	6165	33.4	4	217	2482	2592.1
415	600	4404	3309	1995	6868	37.6	4	196	2607	2922.9
416	570	16	7868	2392	5993	33.4	4	217	2327	2308.6
417	260	13	12846	5485	6478	31.7	3.958	200	2146	2190.7
418	620	294	2506	561	6576	33.4	4	217	2640	2821.0
419	460	4250	3207	2854	6679	38.3	2.992	209	2855	2822.8
420	220	5707	9802	6253	6495.99	37.3	3.958	225	2745	2570.1
421	250	4353	8565	3854	5899	33.4	3.958	217	2135	2185.5
422	870	1345	4882	2168	6441	33.4	4	217	2858	3046.4
423	210	3251	2177	1027	6555	33.4	4	217	2370	2423.0
424	360	375	5585	2915	6551	33.4	4	217	2131	2060.9

425	220	7774	8288	5512	6669.36	37.3	3.958	225	2895	2724.5
426	1000	194	4121	437	6132	33.4	4	217	2854	3004.2
427	220	6956	7971	6154	6754	37.3	4	225	2800	2734.8
428	230	1042	8098	3320	6047	33.4	4	217	1906	1952.2
429	390	842	8112	1063	4243	35.3	4	233	2014	1955.3
430	260	3173	6442	3369	5671	33.4	4	217	1927	1937.7
431	200	1218	6957	3388	6680	31.7	3.958	200	2030	1970.9
432	210	11395	5437	3969	6264	33.4	3.958	217	2970	2704.7
433	210	1278	9934	4033	6574	33.4	3.958	217	2138	2222.5
434	917	381	1435	1673	4700	42.5	4	185	1966	1964.3
435	210	1501	7542	3658	6372	33.4	4	217	1932	1980.2
436	230	1588	13390	6561	6649	31.7	6.276	200	2182	2040.6
437	280	48	9522	2819	6340	31	4	225	2220	2048.7
438	530	59	9787	2995	6621	33.4	4	217	2496	2465.2
439	560	4910	2195	1328	6653	37.3	6.276	225	3045	2967.0
440	185	3938	3563	2636	6248	33.4	4	217	2025	2199.7
441	880	1976	7200	3435	6314	33.4	3.958	217	2855	2956.5
442	280	10715	275	239	7190	37.3	3.958	225	3206	3389.4
443	220	6197	3640	1867	5928	33.4	3.958	217	2189	2348.3
444	187	48	2360	210	4971	27.6	4	160	2195	2170.2
445	540	1444	5431	2216	6454	37.3	4	225	2495	2646.3
446	230	8755	7985	4639	6547	37.3	6.276	225	2424	2594.6
447	230	3591	5986	3370	6501	33.4	3.958	217	2183	2227.5
448	330	2	1758	621	6591	31.7	3.958	200	2200	2333.6
449	180	5690	5510	3174	6830	33.4	3.958	217	2322	2636.2
450	270	5133	5154	2896	6926	33.4	3.958	217	2575	2719.2
451	250	1206	10069	4984	6666	33.4	3.958	217	2143	2276.1
452	220	3887	1871	720	4912	33.4	2.992	217	2186	2125.5
453	200	36	3937	1917	6258	31.7	2.992	200	1864	2001.4
454	300	5703	5889	3569	6523	37.3	4	225	2580	2667.4
455	1025	657	4038	4001	6282	37.6	3.958	196	2761	2718.2
456	250	3402	3670	2573	6670	33.4	2.992	217	2541	2474.8
457	200	8026	1529	1622	6448	37.3	3.958	225	2805	2802.6
458	200	224	6576	736	5191	27.6	3.958	160	2159	2090.7
459	260	9896	7404	5257	6679	37.3	3.958	225	2895	2893.1
460	310	349	2446	575	5855	33.4	4	217	2257	2133.4
461	120	16	1043	83	6100	27.6	3.958	160	2031	2096.6
462	306	0	2404	221	6056	27.6	4	160	2202	2247.5
463	750	1021	4883	3052	6642	37.3	3.958	225	2819	2889.9
464	480	3267	5539	2814	7595	37.3	4	225	2953	3069.0
465	240	1468	12385	7059	6631	33.4	3.958	217	2325	2385.0
466	250	4	4096	1311	6589	31.7	4	200	2252	2113.9
467	425	0	4171	355	5732	27.6	4	160	2274	2311.4
468	720	3882	3361	1502	6500	33.4	3.958	217	3175	3129.9
469	255	773	10770	5105	6053	33.4	3.958	217	2095	2141.8
470	230	1282	450	324	6592	31.7	2.992	200	2617	2470.8
471	340	4878	690	351	6497	33.4	3.958	217	3045	2768.2
472	410	79	2401	146	5650	27.6	3.958	160	2271	2275.5

473	350	4082	4018	1924	6201	33.4	3.958	217	2608	2442.7
474	240	1512	12363	6367	6359	31.7	3.958	200	2273	2240.2
475	435	306	5694	478	5730	27.6	3.958	160	2287	2275.6
476	300	103	9284	2107	5215	28.1	3.958	160	1937	1984.6
477	260	5603	3478	1878	6649	33.4	3.958	217	2484	2689.4
478	290	4950	6300	3604	6589	37.3	4	225	2745	2613.7
479	200	829	6447	3249	6587	33.4	4	217	1924	1904.2
480	250	1424	746	285	5994	33.4	2.992	217	2279	2372.6
481	260	7712	8189	14854	6718	37.3	3.958	225	2939	2879.9
482	1050	1500	13503	6360	6827	31.7	3.958	200	3283	3134.1
483	990	659	4529	2183	5027	33.4	4	217	2417	2535.5
484	200	507	2873	1006	6020	35.3	4	233	2020	1988.7
485	650	5430	2316	1753	7000	38.3	4	209	3162	3145.1
486	320	7829	11550	6295	6874	37.3	4	225	2934	2860.1
487	840	966	1334	868	6672	33.7	4	175	2831	2735.1
488	275	3666	10434	5822	6856	33.4	3.958	217	2848	2550.6
489	245	539	9437	4700	5668	33.4	2.992	217	2228	2061.7
490	830	5214	2615	1577	6510	33.4	4	217	3089	3319.5
491	345	4220	4701	1241	6256	33.4	3.958	217	2506	2523.7
492	410	2921	10728	5235	5893	33.4	6.276	217	2178	2118.8
493	100	2996	333	184	6371	33.4	2.441	217	2615	2535.2
494	340	2043	3277	1416	6363	33.4	3.958	217	2306	2351.3
495	440	962	755	278	6076	33.4	4	217	2517	2472.3
496	620	3491	5648	2790	6587	37.3	3.958	225	2739	2912.7
497	310	4672	5528	2515	6639	33.4	3.958	217	2535	2579.9
498	220	43	8458	3942	6256	31.7	4	200	1726	1867.3
499	450	1196	6187	693	5897	33.4	4	217	2208	2433.9
500	280	648	2146	966	6773	31.7	2.441	200	2275	2546.4
501	320	7	7303	2826	6383	33.4	4	217	1899	2026.3
502	355	913	9831	3126	6831	33.4	3.958	217	2336	2408.6
503	210	1266	7465	3367	6522	33.4	4	217	1914	2015.6
504	760	193	10539	5891	6637	33.4	4	217	2440	2700.8
505	430	2150	1628	402	6263	33.4	3.958	217	2493	2617.9
506	285	1412	1511	364	6494	33.4	2.992	217	2385	2565.3
507	750	1947	4653	3187	6015	33.4	3.958	217	2717	2673.3
508	393	0	5603	986	5635	26.4	3.958	160	2198	2096.8
509	350	2036	13508	7146	6727	37.3	4	225	2651	2697.5
510	190	254	1576	561	6448	33.4	4	217	2116	2117.5
511	460	157	5083	579	5185	27.6	3.958	160	2256	2260.7
512	260	1181	13398	6391	6468	33.4	4	217	2349	2373.6
513	300	3468	13286	7414	6739	37.3	3.958	225	2735	2760.9
514	230	52	17284	8953	6326	33.4	3.958	217	2404	2324.9
515	780	286	7411	2794	6407	33.4	4	217	2906	2747.4
516	220	1930	7304	4083	6026	33.4	3.958	217	1970	1880.6
517	100	93	6567	722	5766	27.6	3.958	160	1984	2029.3
518	375	0	1943	295	5095	26.4	3.958	160	2216	2159.7
519	240	3576	8424	4296	6131	33.4	3.958	217	2243	2175.7
520	305	113	13999	7154	7006	33.4	3.958	217	2354	2474.9

521	310	1488	4326	1977	6267	33.4	4	217	2235	2130.8
522	150	26	3724	384	5922	27.6	3.958	160	2047	2088.5
523	235	5866	4425	2960	6831	33.4	3.958	217	2684	2735.8
524	295	155	4396	761	5930	26.4	4	160	2114	2118.9
525	340	4731	1654	1586	6848	33.4	4	217	2661	2831.7
526	400	0	4230	495	5050	26.4	4	160	2246	2209.5
527	290	2369	4897	2503	6544	37.3	3.958	225	2392	2386.7
528	470	107	2572	442	5250	27.6	3.958	160	2287	2267.4
529	680	3872	7652	6963	6985	38.3	3.958	209	2823	2895.2
530	240	1095	9855	4642	6235	33.4	4	217	2125	2131.4
531	360	2	1139	159	5066	27.6	3.958	160	2217	2225.9
532	250	5810	4678	2708	6456	37.3	3.958	225	2566	2642.5
533	480	1188	7060	826	6664	33.4	6.276	217	2689	2473.5
534	520	4978	5393	3748	6870.5	37.3	3.958	225	3033	2980.6
535	450	1956	3219	2163	6262	33.4	4	217	2577	2361.5
536	390	0	3044	286	6229	27.6	3.958	160	2267	2247.1
537	290	4206	7444	5501	5833	33.4	4	217	2025	2053.1
538	330	2623	4725	2343	5964	33.4	4	217	2291	2129.7
539	285	67	13287	5993	6516	33.4	4	217	2306	2320.1
540	400	134	6250	3106	6510	31.7	4	200	2303	2065.2
541	255	4657	4264	1748	6209	33.4	3.958	217	2507	2405.5
542	590	3046	1549	526	6769	37.3	4	225	3196	3140.0
543	420	0	2700	413	6060	26.4	3.958	160	2269	2181.8
544	220	1263	10656	5402	6828	33.4	3.958	217	2307	2326.3
545	100	1870	630	43	5907	27.6	4	160	2320	2217.7
546	170	4322	2441	1448	6741	33.4	2.992	217	2780	2649.5
547	280	2013	10115	4946	6256	33.4	3.958	217	2056	2265.4
548	480	2333	1690	809	6628	37.3	4	225	2641	2869.4
549	225	2129	2927	1098	6083	33.4	4	217	2071	2168.8
550	175	5593	7177	3538	6606	33.4	6.276	217	2183	2329.7
551	500	1259	4941	2693	6559	31.7	2.992	200	2511	2529.8
552	410	4	4367	1943	6075	33.4	3.958	217	1990	2105.5
553	250	1167	1865	675	5982	33.4	4	217	2056	2138.2
554	700	371	7321	3199	5963	33.4	4	217	2291	2430.3
555	200	7313	1726	1267	6783	31.7	3.958	200	2638	2602.6
556	520	3093	13271	7312	6642	37.3	6.276	225	2525	2619.8
557	940	1260	2240	1772	7122	33.7	4	175	2831	2929.9
558	255	4491	4787	2509	6244	33.4	3.958	217	2192	2350.6
559	570	1557	3338	2464	6194	37.6	3.958	196	2580	2573.5
560	240	2165	2835	1539	6815	31.7	3.958	200	2166	2311.4
561	340	33	8167	2687	6318	33.4	4	217	2000	2104.8
562	260	3524	6374	3181	6787	33.4	3.958	217	2194	2375.3
563	260	736	1663	715	6045	33.4	3.958	217	1864	2123.9
564	200	5	5311	1816	6828	31.7	3.958	200	2224	2047.0
565	280	1635	4704	1594	6240	33.4	3.958	217	2019	2179.4
566	1058	66	6567	5910	4770	42.5	4	185	2152	1997.9
567	205	415	13424	6511	6213	33.4	3.958	217	2145	2211.9
568	760	4488	4295	2925	6548	37.3	3.958	225	2919	3161.7

569	340	137	2917	300	5250	27.6	4	160	2232	2260.8
570	250	2303	1382	618	6709	37.3	2.992	225	2684	2772.3
571	230	2759	401	262	6517	33.4	2.441	217	2959	2707.2
572	310	1374	8878	8017	6733	31.7	4	200	1973	2177.7
573	315	210	2123	191	6000	27.6	4	160	2233	2264.6
574	150	103	4569	356	5593	27.6	3.958	160	2020	2100.0
575	540	443	2361	756	6055	33.4	4	217	2428	2508.6
576	220	5723	8477	4078	5815.8	33.4	3.958	217	2329	2160.4
577	300	3349	1316	505	6353	37.3	4	225	2804	2680.5
578	185	2025	819	405	6315	33.4	3.958	217	2520	2271.3
579	560	151	9264	3974	6334	37.3	3.958	225	2533	2500.5
580	340	772	5767	2699	6309	33.4	4	217	2316	2031.9
581	230	9031	6566	3986	6390	37.3	3.958	225	2542	2699.5
582	720	2661	9434	6736	6690	37.3	4	225	2917	2906.9
583	190	7317	1784	994	6254	33.4	4	217	2649	2582.9
584	365	4041	2073	1780	6502	33.4	4	217	2681	2606.2
585	680	1560	9501	5292	6356	37.3	4	225	2740	2715.0
586	930	2723	7037	4032	6501	37.3	3.958	225	3260	3144.2
587	900	2016	3522	4417	6980	38.3	3.958	209	2867	3080.9
588	285	1120	6011	2525	6440	33.4	3.958	217	2281	2070.6
589	140	148	10452	669	5651	27.6	3.958	160	2150	2092.2
590	1100	417	2400	463	6282	33.4	4	217	3293	3107.9
591	300	1717	11591	4660	5855	33.4	4	217	2213	2248.8
592	310	1001	8266	4464	5785	33.4	4	217	1950	1910.7
593	760	84	4855	1359	5434	33.4	2.992	217	2644	2568.6
594	1110	1100	1545	618	6874	33.4	4	217	3571	3393.5
595	250	1433	4254	1651	6424	31.7	2.992	200	2549	2293.8
596	230	211	8969	3552	6644	33.4	3.958	217	2096	2114.2

Table B.2: Data Used for Testing the ANFIS Model and the Predicted BHP

SN	WHP	Qw	Qo	Qg	Depth	API	ID	Tres	BHP	Pred. BHP
1	280	1675	3195	230	5064	27.6	4	160	2300	2304.6
2	170	2246	9701	5190	6537	31.7	3.958	200	2230	2140.8
3	700	3738	1341	992	6415	33.4	4	217	3052	3111.5
4	260	3142	2275	1119	6548	33.4	2.992	217	2629	2592.5
5	190	24	12215	5631	6242	33.4	4	217	2049	2131.2
6	525	1040	14260	8099	7358	37.3	3.958	225	2810	2947.5
7	310	2550	13798	7810	6815	37.3	4	225	2679	2725.8
8	550	287	7481	4301	6054	33.4	4	217	2306	2135.4
9	396	488	2763	323	5755	26.4	3.958	160	2301	2201.0
10	960	45	7525	2709	6212	37.3	3.958	225	2950	2905.9
11	170	3530	7199	2757	6710	33.4	4	217	2460	2310.4

12	920	359	9910	8275	5986	38.7	4	220	2566	2781.7
13	280	10144	5156	2949	6700	33.4	3.958	217	2965	2919.4
14	510	1620	994	800	6189	33.4	4	217	2728	2607.9
15	350	2224	13546	6638	6593	37.3	3.958	225	2621	2689.8
16	336	834	5630	1115	4888	28.1	3.958	160	2174	2161.0
17	230	561	839	421	6370	33.4	3.958	217	2240	2203.3
18	930	2105	4495	4166	6186	38.7	3.958	220	2731	2895.7
19	320	442	14791	2026	6191	33.4	4	217	2726	2369.3
20	220	4852	796	426	6021	33.4	3.958	217	2690	2434.8
21	191	67	6796	816	6451	26.4	4	160	2040	2063.7
22	590	2732	6168	3824	6487	33.4	3.958	217	2484	2540.1
23	370	0	1484	139	5818	27.6	4	160	2268	2290.9
24	375	6385	6890	5209	6864	33.4	4	217	2838	2840.6
25	560	3641	1809	2238	6543	38.7	2.992	220	2846	2996.9
26	640	1076	14517	7476	6919	37.3	3.958	225	3149	2966.5
27	938	338	5300	4510	4850	42.5	4	185	2094	2041.4
28	280	4260	17040	9491	6613	37.3	6.276	225	2588	2570.7
29	315	9570	3966	2158	7087	31.7	4	200	3146	2887.9
30	400	291	2806	219	5866	27.6	4	160	2345	2320.5
31	480	2870	9664	5943	6575	37.3	3.958	225	2584	2684.4
32	720	4662	2668	2636	6831	38.3	4	209	3196	3131.9
33	380	1887	5661	668	5524	27.6	4	160	2312	2330.8
34	240	4941	7110	4046	6215	33.4	4	217	2244	2284.6
35	320	8507	6876	3782	6856	31.7	4	200	2997	2647.8
36	220	3742	3112	1609	5643	33.4	4	217	2212	2106.4
37	230	2778	10203	4622	6557	33.4	3.958	217	2384	2360.3
38	590	4601	6460	3159	6879	37.3	3.958	225	3125	3030.6
39	240	5112	3794	1559	6116	31.7	4	200	2408	2201.9
40	820	70	11633	3490	6196	37.3	4	225	2953	2822.0
41	620	3802	2598	1892	6413	37.3	4	225	2995	2972.8
42	360	5168	348	286	6492	33.4	4	217	3152	2808.3
43	890	249	988	556	6078	37.3	4	225	2784	2818.4
44	300	9735	1598	2459	6588	37.3	3.958	225	2965	3048.2
45	285	8861	6739	3363	7044	33.4	3.958	217	2984	2980.0
46	570	6065	2513	3526	6090	37.6	3.958	196	2510	2433.4
47	240	724	3803	297	5087	28.1	4	160	2104	2257.0
48	600	40	9992	5526	6749	37.3	3.958	225	2609	2655.8
49	420	51	1360	80	5740	27.6	3.958	160	2430	2283.3
50	283	0	1119	107	5097	26.2	3.958	160	2114	2115.3
51	390	3600	1162	293	6199	33.4	3.958	217	2884	2652.8
52	220	5210	2590	1911	6745	33.4	4	217	2730	2683.8

53	1020	880	1818	1267	5042	37.3	4	225	2783	2552.7
54	400	2846	4703	2789	6418	33.4	3.958	217	2480	2337.0
55	1394	0	1000	1045	8478	47.5	2.992	189	3698	3430.6
56	265	64	7056	3697	6006	31.7	4	200	1818	1732.0
57	520	317	12683	6050	5684	33.4	4	217	2224	2345.6
58	457	0	1822	250	5673	27.6	3.958	160	2414	2281.1
59	220	2144	7782	3058	6289	33.4	3.958	217	2349	2100.7
60	480	6114	2389	2045	6725	37.3	3.958	225	2967	3074.7
61	390	30	9821	5019	6517	31.7	4	200	2316	2182.1
62	493	1116	3533	1131	6062	35.3	4	233	2511	2486.7
63	360	8	3941	571	5007	26.4	3.958	160	2138	2123.1
64	280	3309	7758	4259	6760.2	37.3	3.958	225	2571	2478.6
65	280	588	14121	6312	6281	33.4	3.958	217	2289	2330.9
66	535	4183	4217	2952	5728	33.4	3.958	217	2289	2399.3
67	255	1897	1603	545	6333	33.4	4	217	2341	2335.9
68	300	569	11799	6171	6363	33.4	4	217	2424	2284.3
69	390	1546	5354	2827	6603	31.7	4	200	2293	2215.6
70	1200	337	2522	2335	5981	38.1	4	207	2635	2762.4
71	500	697	2161	640	6222	33.4	4	217	2452	2547.9
72	900	65	6400	5472	5920	37.3	4	225	2789	2538.8
73	820	58	2175	574	6724	38.3	4	209	3103	2900.8
74	200	1010	8170	915	5921	27.6	4	160	2310	2164.1
75	360	420	12720	6958	6703	37.3	4	225	2652	2554.4
76	950	476	803	472	6537	31.7	4	200	2922	3008.4
77	360	4818	8064	4782	6958.5	33.4	3.958	217	3076	2679.3
78	350	2433	6256	1076	4882	26.4	3.958	160	2129	2166.0
79	260	1275	973	546	6739	33.4	3.958	217	2380	2411.2
80	310	2871	2704	1941	6698	31.7	3.958	200	2342	2373.6
81	500	80	4608	2088	6728	31.7	4	200	2366	2441.1
82	195	2168	4714	2154	6716	33.4	3.958	217	2169	2171.4
83	255	184	3504	890	6105	33.4	4	217	2019	2074.5
84	1410	1532	3698	532	6682	33.4	4	217	3589	3577.0
85	1000	13	6423	2736	6440	37.3	4	225	2729	3000.7
86	250	2084	1776	938	6277	33.4	2.992	217	2263	2419.5
87	1090	1206	1689	792	6555	33.4	2.992	217	3140	3313.1
88	428	26	13045	4983	6199	33.4	3.958	217	2210	2378.5
89	370	2198	4847	1822	5856	33.4	4	217	2107	2197.4
90	740	1115	14815	7630	6599	37.3	4	225	2836	2991.5
91	400	1294	3645	470	5096	37.3	2.441	225	2282	2540.2
92	320	2339	1173	569	5816	33.4	4	217	2262	2297.9
93	405	5598	2988	1461	6556	33.4	3.958	217	2673	2806.9

94	540	3346	7589	3332	6688	37.3	3.958	225	2686	2786.4
95	520	646	6227	3045	6592	37.3	4	225	2330	2491.8
96	200	4460	3419	1741	6709	31.7	3.958	200	2395	2386.9
97	440	72	7091	3241	5948	31.7	4	200	1999	1970.7
98	370	6844	547	497	7164	31.7	4	200	2801	2955.6
99	420	238	3933	397	6668	35.3	6.276	233	2334	2484.4
100	205	2908	5060	2454	6527	33.4	4	217	2155	2184.5
101	225	2040	7360	3165	6610	33.4	4	217	2163	2136.5
102	680	1551	637	364	6535	33.4	3.958	217	2958	2997.2
103	200	10171	2039	779	5566	33.4	3.958	217	2349	2380.9
104	315	298	9008	4702	6618	33.4	3.958	217	1972	2173.3
105	270	4207	4156	1671	6407	33.4	4	217	2359	2464.3
106	235	1907	2581	524	6230	31.7	2.992	200	2379	2428.6
107	480	602	910	248	6034	33.4	3.958	217	2458	2490.1
108	1180	8	7706	5942	6327	37.3	3.958	225	2827	2974.1
109	340	1904	3257	967	6601	31.7	2.992	200	2417	2603.1
110	465	6	5852	2674	6135	31.7	4	200	1957	2090.3
111	260	2067	8371	3072	6409	33.4	3.958	217	2053	2207.6
112	1180	63	2915	2198	6733	38.3	3.958	209	3046	3037.7
113	235	1718	6788	2125	6611	33.4	3.958	217	2100	2206.2
114	215	281	7323	3603	6390	33.4	4	217	1705	1866.4
115	340	380	4090	1910	6621	33.4	3.958	217	1993	2198.9
116	315	3342	1661	772	6809	31.7	2.992	200	2547	2727.2
117	215	1111	6998	3408	6514	33.4	3.958	217	1818	1964.3
118	230	200	5522	2170	6608	33.4	4	217	1846	1989.3
119	320	834	5535	2751	6210	33.4	4	217	1839	1964.0
120	220	1835	3777	1254	6518	33.4	3.958	217	2051	2245.8
121	230	2113	4101	1870	6162	33.4	6.276	217	1819	1828.4
122	405	863	7596	3274	6232	33.4	3.958	217	1999	2141.0
123	265	742	5288	2300	6558	33.4	4	217	1898	2043.5
124	285	568	6272	2101	6484	33.4	4	217	2123	2099.2
125	465	150	5217	2368	6633	33.4	3.958	217	2254	2338.3
126	400	1404	1780	895	6854	33.4	2.992	217	2541	2781.5
127	200	663	4007	593	5900	27.6	4	160	2387	2166.4
128	490	8	3922	2036	6583	31.7	4	200	2137	2376.7
129	246	99	9791	2379	6380	33.4	4	217	2106	2147.2
130	340	4356	2844	1561	6209	33.4	4	217	2341	2498.1
131	800	596	1102	889	6933	38.3	4	209	3011	2985.6
132	215	1379	3906	1066	6392	33.4	2.992	217	2168	2352.6
133	180	459	3951	364	5071	27.6	4	160	2076	2173.5
134	200	6895	3505	1717	6136	33.4	3.958	217	2283	2465.2

135	330	4798	1060	328	6382	37.3	3.958	225	2738	2796.1
136	1149	86	1140	7183	4790	42.5	3.958	185	1970	1750.2
137	350	47	5153	830	6950	33.4	4	217	2233	2472.0
138	1100	140	9860	2357	6206	37.3	4	225	2885	3078.8
139	620	863	6638	2303	6368	33.4	4	217	2504	2576.6
140	610	520	12824	12016	6806	38.3	3.958	209	2838	2788.1
141	380	9500	3000	1248	6517	33.4	4	217	2810	2944.6
142	300	8116	3512	1914	6505	33.4	3.958	217	2517	2793.1
143	560	3605	5296	5131	6782	38.3	4	209	2810	2656.7
144	1030	1855	9883	5673	5418	37.3	4	225	2563	2829.9
145	330	2239	1961	1024	6482	33.4	3.958	217	2379	2452.9
146	480	2831	5352	2665	6559	37.3	4	225	2424	2658.2
147	340	3041	1594	725	5875	33.4	2.992	217	2351	2516.6
148	915	2269	973	506	7151	33.4	2.992	217	3270	3555.6
149	310	5212	8397	4904	6719	37.3	3.958	225	3023	2678.7
150	250	452	5652	639	6063	31.7	2.992	200	2266	2320.9
151	720	5676	6324	4781	6870	38.3	3.958	209	2933	2996.4
152	210	1638	7311	3817	7030	31.7	3.958	200	1858	2104.3
153	370	1137	4463	2731	6472	33.4	3.958	217	2063	2131.5
154	570	266	9584	5894	6584	37.3	3.958	225	2884	2573.1
155	380	2053	7541	2850	6637	31.7	3.958	200	2379	2316.4
156	240	1082	3078	416	6360	33.4	4	217	2257	2292.1
157	1200	181	2401	2168	6701	38.3	2.992	209	3014	3080.5
158	210	192	8527	3624	6064	33.4	4	217	1754	1892.6
159	840	1339	8292	6219	6344	37.3	2.992	225	2869	2896.1
160	330	540	5600	2923	5843	33.4	4	217	1796	1822.3
161	500	44	5474	2907	6738	31.7	4	200	2152	2319.7
162	270	2396	7422	3592	6361	33.4	3.958	217	2030	2121.6
163	850	413	3887	1458	6451	33.4	3.958	217	2691	2980.2
164	380	1721	3268	2114	6769	31.7	4	200	2278	2375.3
165	200	1803	2057	883	6355	31.7	2.992	200	2177	2340.6
166	230	3362	4624	2210	6852	31.7	3.958	200	2223	2338.6
167	780	5549	4119	3315	6920	38.3	4	209	3325	3176.9
168	410	11	10989	5593	5803	31.7	4	200	1865	2090.8
169	460	4595	1805	998	6736	33.4	4	217	2833	2937.6
170	190	569	3496	1374	6071	33.4	3.958	217	1940	1932.6
171	620	24	3997	1447	6496	31.7	4	200	2336	2626.5
172	250	1758	4203	1765	6753	31.7	4	200	2107	2238.3
173	1350	32	3206	4148	4650	42.5	3.958	185	2199	1951.8
174	280	4636	2486	1377	6007	33.4	3.958	217	2205	2395.9
175	350	2622	2774	802	5850	33.4	3.958	217	2236	2356.7

176	395	479	14962	7616	6769	37.3	3.958	225	2340	2671.7
177	470	2481	523	118	6022	33.4	3.958	217	2630	2650.2
178	320	3568	826	9	6668	33.4	4	217	2851	2758.3
179	420	5364	7081	3222	6642	37.3	2.992	225	2960	2867.7
180	430	1051	5131	2068	5835	31.7	2.992	200	2193	2267.9
181	250	1269	6764	3578	5947	33.4	3.958	217	1746	1820.6
182	230	167	15004	6017	6624	33.4	6.276	217	2050	2059.3
183	240	202	4979	831	6315	33.4	4	217	2079	2152.2
184	260	334	5966	2894	6546	31.7	4	200	1903	1919.1
185	285	2593	5560	2652	6420	33.4	3.958	217	2122	2187.4
186	240	283	7363	3335	6648	31.7	4	200	1913	1954.0
187	350	3979	1788	681	6533	33.4	4	217	2533	2697.4
188	1100	80	8820	1349	6545	37.3	3.958	225	2940	3227.0
189	185	3084	815	283	6259	33.4	2.992	217	2302	2512.1
190	200	3017	4583	2058	5985	33.4	3.958	217	2303	2081.2
191	780	1981	2532	1068	4933	37.3	4	225	2323	2522.5
192	260	2287	3893	1978	5985	33.4	3.958	217	1928	2065.4
193	195	4651	9191	4430	6575	33.4	6.276	217	2105	2184.8
194	210	3362	5259	1935	6519	33.4	4	217	2402	2320.0
195	680	1843	790	848	6179	37.6	2.992	196	2702	2785.5
196	490	5879	1591	364	6840	33.4	4	217	2934	3093.9
197	195	1370	1675	693	6342	33.4	4	217	2050	2179.5
198	360	249	11620	3788	6519	33.4	4	217	2179	2356.4
199	460	1544	4196	2056	6302	33.4	3.958	217	2224	2378.1

APPENDIX C

PROGRAM LISTING

C.1: Program for Calculating BHP in Prosper

```
Dim i As Integer
Dim j As Integer
Dim k As Integer = 10
Dim arr(6) As Integer
arr(0) = 0
arr(1) = 1
arr(2) = 2
arr(3) = 4
arr(4) = 5
arr(5) = 9
arr(6) = 10
Dim aa As Integer
xlApp = New Microsoft.Office.Interop.Excel.Application
xlApp.Visible = True
xlWorkBook = xlApp.Workbooks.Open("C:\Users\shamat0e\Desktop\AI\Project\data_for_Trend_Anls_Prosper.xls")
Pxserver.connect()
Pxserver.DoCommand("PROSPER.START")
Pxserver.DoCommand("PROSPER.OPENFILE(""C:\Users\shamat0e\Desktop\AI\Project\Prosper_Sample.out"")")
For i = 1 To 5
   xlWorkSheet = xlWorkBook.Sheets(i)
   For aa = 0 To 6
      For j = 2 To 10
         Pxserver.setValue("PROSPER.ANL.GRD.Tubing", arr(aa))
         Pxserver.setValue("PROSPER.ANL.GRD.Pres", xlWorkSheet.Cells(j, 1).value)
         Pxserver.setValue("PROSPER.ANL.GRD.WC", xlWorkSheet.Cells(j, 2).value)
         Pxserver.setValue("PROSPER.ANL.GRD.Rate", xlWorkSheet.Cells(j, 3).value)
         Pxserver.setValue("PROSPER.ANL.GRD.GOR", Val(xlWorkSheet.Cells(j, 4).value))
         Pxserver.setValue("PROSPER.PVT.Input.Solgor", Val(xlWorkSheet.Cells(j, 4).value))
         Pxserver.setValue("PROSPER.SIN.EQP.Down.Data[1].Depth", xlWorkSheet.Cells(j, 5).value)
         Pxserver.setValue("PROSPER.SIN.EQP.Devn.Data[1].Md", xlWorkSheet.Cells(j, 5).value)
         Pxserver.setValue("PROSPER.SIN.EQP.Devn.Data[1].Tvd", xlWorkSheet.Cells(j, 5).value)
         Pxserver.setValue("PROSPER.SIN.EQP.Geo.Data[1].Md", xlWorkSheet.Cells(j, 5).value)
         Pxserver.setValue("PROSPER.SIN.EQP.Down.Data[1].TID", xlWorkSheet.Cells(j, 7).value)
         Pxserver.DoCommand("PROSPER.ANL.GRD.CALC")
         Dim Grad_Count
         Grad_Count = Pxserver.getValue("PROSPER.OUT.GRD.RESULTS[i][j][k].NUM") - 1
         xlWorkSheet.Cells(j, k) = Pxserver.getValue("PROSPER.OUT.GRD.Results[0][0][0].Pres[" & Grad_Count & "]")
      Next j
      k += 1
   Next aa
   k = 10
Next i
```

C.2: Main Matlab Program for Generating the ANFIS model

```
clc
clear all
close all

[data, text]= xlsread('data_for_FL.xls');

IP_data = data(:,1:8);
TRG_data = data(:,9);
trn_in = IP_data(1:596,:);
trn_out = TRG_data(1:596,:);
tst_in = IP_data(597:795,:);
tst_out = TRG_data(597:795,:);

fismat2 = genfis2(trn_in,trn_out,0.6);
out_fis2 = anfis([trn_in trn_out],fismat2);
genfis2_Pred_trn_out = evalfis(trn_in,out_fis2);
genfis2_Pred_tst_out = evalfis(tst_in,out_fis2);

fismat2 = setfis(fismat2, 'input', 1, 'name','WHP')
fismat2 = setfis(fismat2, 'input', 2, 'name','Qw')
fismat2 = setfis(fismat2, 'input', 3, 'name','Qo')
fismat2 = setfis(fismat2, 'input', 4, 'name','Qg')
fismat2 = setfis(fismat2, 'input', 5, 'name','Dpth')
fismat2 = setfis(fismat2, 'input', 6, 'name','api')
fismat2 = setfis(fismat2, 'input', 7, 'name','ID')
fismat2 = setfis(fismat2, 'input', 8, 'name','Tres')
fismat2 = setfis(fismat2, 'output', 1, 'name','BHP')

[C,S] = subclust(trn_in, 0.6)

getfis(fismat2)
showrule(fismat2)
plotfis(fismat2)
ruleview(fismat2)


success = xlswrite ('results fuzzy.xls',trn_out,'WC_GOR_QL_1', 'A2');
success = xlswrite ('results fuzzy.xls',genfis2_Pred_trn_out,'WC_GOR_QL_1', 'B2');
success = xlswrite ('results fuzzy.xls',tst_out,'WC_GOR_QL_1', 'f2');
success = xlswrite ('results fuzzy.xls',genfis2_Pred_tst_out,'WC_GOR_QL_1', 'g2');
```

C.3: Matlab Program for the ANFIS Trend Analysis

```
clc
clear all
close all

[data, text]= xlsread('data_for_FL.xls');
[trend_data, text]= xlsread('data_for_Trend_Anls.xls');

IP_data = data(:,1:8);
TRG_data = data(:,9);
trn_in = IP_data(1:596,:);
trn_out = TRG_data(1:596,:);

fismat2 = genfis2(trn_in,trn_out,0.6);
out_fis2 = anfis([trn_in trn_out],fismat2);
genfis2_Pred_Trend_out = evalfis(trend_data,out_fis2);

success = xlswrite ('data_for_Trend_Anls.xls',genfis2_Pred_Trend_out,'gas rate', 'J2');
```

C.4: Matlab Program for the Generating the Histograms

```
clc
[data, text]= xlsread('data for histogram.xls');
Duns_Ros = data(:,1);
Hagedorn_Brown = data(:,2);
Fancher_Brown = data(:,3);
Mukhairji_Brill =  data(:,4);
Beggs_Brill = data(:,5);
Orkisweski = data(:,6);
PETEX_II = data(:,7);
ANFIS_Testing = data(:,8);
ANFIS_Training = data(:,9);

figure
histfit(Duns_Ros)
h = findobj(gca,'Type','patch');
set(h,'FaceColor','w','EdgeColor','k')
title('Duns and Ros');
xlabel('Relative Error %');
ylabel('Frequency')
set(gcf, 'color', 'White')
```

CURRICULUM VITAE

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